Inline Water Quality Monitoring System (IWQMS)

Abstract

Inline Water Quality Monitoring System (IWQMS) is a system that performs scheduled testing for the water quality in the infrastructure pipes without human interventions. This system was designed to monitor the water quality based on the working area requirements and the user's aims. It is supposed to observe water in power plants working by steam, biomedical systems, pharmaceuticals production lines, food factories, desalination plant, water wall, and laboratories. However, water quality depends on the physical and chemical parameters of the water. Two of these parameters are concentration of salts in the water or total dissolved solid (TDS) and electrical conductivity (EC). IWQMS uses these two parameters to determine the water quality by measuring the electrical waves in the tested water sample. It consists of three designed subsystems operating together; these subsystems are mechanical, electronic and software. The mechanical subsystem is designed to automatically collect water samples without human intervention from the pipes. The electronic subsystem is used for controlling and sensing. Sensing is performed using a sensor especially designed to be used for IWQMS. This sensor measures two important parameters TDS and EC. The software subsystem is used to process the collected data, arrange the operations, and store the obtained data for the operator or send it through wireless sensor network. Many iterations and tests were performed on the system and it produced satisfactory results with very small error variation compared with laboratories testing devices.

1. Introduction

As water is the most important compound on the earth and it is crucial to observe its quality to determine changes in it through time. For example, the water desalination plants which use an ion exchanger need continuous observation of the produced water [(1).] Also, the food manufacturing systems need a continuous and accurate water observation because any change of water will make problems in products [(2)]. Moreover, the drinking water must have a limited concentration of parameters for instance and based on the criteria of the Global Health Organization, the concentration of salt in drinking water isn't allowed to pass 1000mg/l, a person needs at least two liters of water per day[(3)]. The agriculture production requires prober water for irrigation [(4)]. On the other hand, many accidents happened in history such as the French water attack when 5000 L of sulphuric acid were dumped in the Meuse River indicates that water observation is very important [(5)].

Based on the pre-mentioned information, water monitoring is very important and requires a regular obtaining of water samples from different areas and applications to be analyzed in labs. But this approach demands cost and work, and doesn't allow reaction in the perfect time. This shortcoming triggered the idea of EARLY WARNING SYSTEM. The research center at the institute of the Protection and Security of the Citizen at the European Commission placed a definition for the Early Warning System as "integrated systems used for online monitoring, collecting data, analysing, interpreting, and communicating monitored data, which can then be used to make decisions early enough to protect public health and the environment, and to minimize unnecessary concern and inconvenience to the public" [(6)].

Generally, water monitoring areas can be split into wide areas or surface areas and specific areas of applications. For the surface water, a sustainable use of water requires monitoring program for the quality, and the main problem is to find a system able to collect large number of samples [(7)]. For instance, Yildiz Technical University in Instanbul developed two designs to solve this problem which are miniboats loaded with sondes with probes and wireless sensor network- (WSN-) based monitoring system on buoys [(7)]. On the other hand, many fixed base systems have been developed as follows:

1- KaptaTM 3000 AC4.
   This system is based on optical measurement using wavelength (Task, 2013).
2- The spectro laser.
   This is based on laser technology was developed in 1999 in Australia and it is used in many old systems around the world.
3- The Event Lab .
   Is based on lab on-chip sensor technology and used in Singapore and Netherlands.

Water monitoring systems require many sensing parts, but the main problem is to find a suitable sensor which can be implemented in these devices [(6)]. Many Multiprobes or sondes were improved in the literature. For example, water EC, temperature, pH, and luminescent dissolved oxygen DO were improved to inspect water quality in the Nam Co Lake, China and Toenepi Stream, New Zealand [(8),(9)]. Moreover, solid state sensors that can be used in water quality monitoring systems were analysed and reviewed [(10), (11)].

This paper is about the design and construction of a system developed to make an automated monitoring for the running water qualities inside the pipes. It is divided into three main parts. First part illustrates the main chemical and physical parameters of the water, and the used technique. The second is about the system construction and design which include a design of the main sensing part, and the final part shows the results and analysis, conclusion then the future work.

2. Chemical and physical properties of the water

There are different chemical and physical parameters monitored in the water to determine its quality. These parameters have been defined in the Water Framework Directive WFD and the US EPA and Turkish regulation [(6)]. Water in European Union is usually monitored using the (2000/60/EC) framework and national water legislation [(6)].
This research will focus on the electrical conductivity of the water as many areas in the world suffer from this problem. This developed system depends on measuring the water's quality by measuring the dissolved salts concentration which produces the water electrical conductivity. If the water contains salts and is affected by electrical charge through two poles, electrical connectors, this will force salts molecules to be collected on the poles. If the potential polarity on the two plates is direct, this will make "Polarization" which is collection of the charge carriers on the side of the poles [(14)]. Figure1 shows the reaction of the dissolved salts in water

under the electrical field effect. The polarization decreases the electrical current through the water after a period of time. To overcome this problem, the potential polarity must be alternating to produce a continuous movement between the two plates and this produces electrical current inside the water.

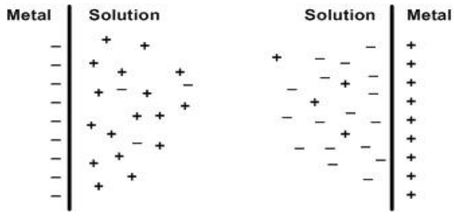

Figure 1 Illustration of charge carriers collection on the two plates [14].

The Electrical conductivity γ is the ability of defined amount of water to convey electrical current. The electrical conductivity is an important factor in this research, because it depends on salt concentration in the water and it is changeable from one sample to another. Electrical conductivity is measured by micro Siemens per cm ($\mu s/cm$) [15]. So, the electrical conductivity is an indirect indicator to the quantity of the dissolved salts. Equation1 represents water electrical conductivity.

$$\gamma = \frac{I}{V}.K \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ldots\ldots.(1)$$

$\gamma : ElectricalConductivityofwaterSample.$

I : Electrical current through the water sample.

V: Voltage difference on the two plates.

K: Cell constant which is calculated from the two plate’s dimensions and the distance between them related to Equation2.

$$K = \frac{L}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

K: Cell constant.

L: Distance between the two plats.

A: Cell area.

(Total Dissolved Solid) or (TDS), represents the charge carrier, it is the weight of dissolved metals in determined amount of water (mg/l). The TDS is defined by measuring the electrical conductivity of water then multiplying it by constant between 0.5 and 1 [1], [3]. Table1 includes water classification based on electrical conductivity and dissolved salts concentration.

Table 1. Water classification based on water conductivity and salt concentration[1].

Water or Aqueous Solution	Conductivity Range at 25 °C		Salt Concentration	
High-Purity Water	0.055	µS/cm	0	mg/l
Fully-Desalinated Water	0.055 – 2	µS/cm	0 – 1	mg/l
Rainwater	10 – 50	µS/cm	5 – 20	mg/l
Ground, Surface and Drinking Water	50 – 1000	µS/cm	20 – 50	mg/l
Sea Water	20 – 60	mS/cm	10 – 40	g/l
Saline Solution	77 – 250	mS/cm	50 – 250	g/l

3. Proposed IWQMS parts

These main parts of the proposed systems are illustrated in Figure 2. These systems are Electronic System, Software System and Electromechanical System as follows:

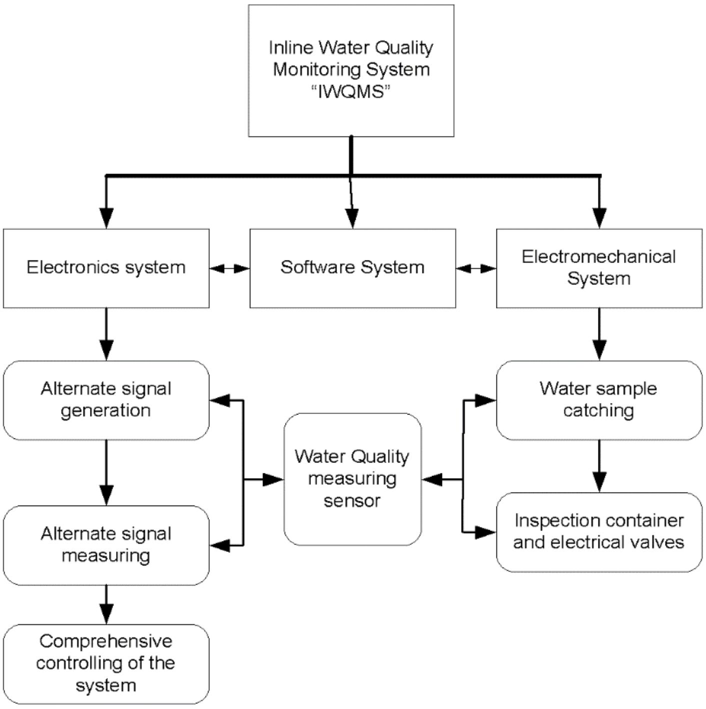

Figure 2 Main parts of the proposed system.

3.1 Electromechanical part

This part is to collect the water samples and its work principle is illustrated in Figure 3 and the work procedure is represented in Figure 4.

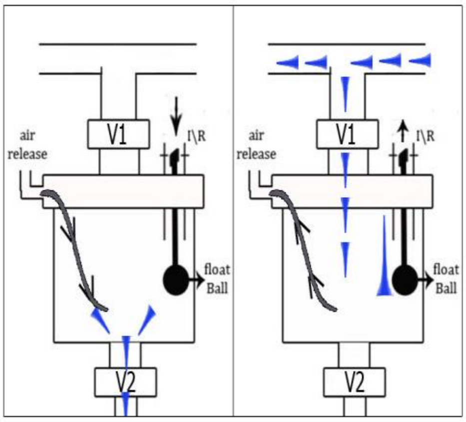

Figure 3. The electromechanical system, the inspection container, and the water movement and the air paths.

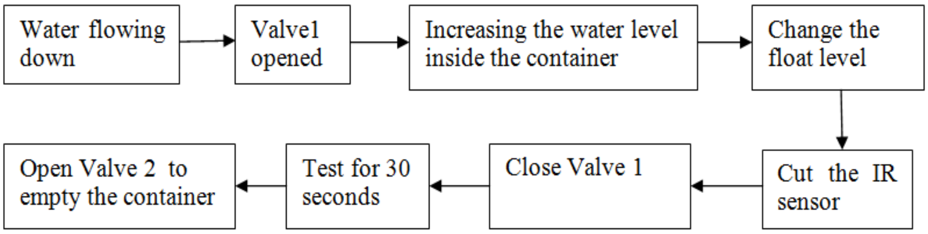

Figure 4. The main procedure of electromechanical part.

3.2 Electrical conductivity Sensor

The charge carriers in the water must be activated by external signal to measure the electrical conductivity of the water. There are many deigns for this sensor with different principles. (Invasive and Non- Invasive Cylindrical Capacitive sensor) is a capacitor which contains two metal plates. When it is immersed in the water, potential between the two plates is supplied by external power source [16]. But the design of (Capacitive Electrode) needs very accurate manufacturing because it is small and complex. Figure 5 describes the internal construction of (Capacitive Electrode). So, this research is designing another shape of plate which is flat plate. The scientific principle of this plate is attracting the charge carriers to the plate through defined paths produced by the potential between the two plates, and this is highly related to the distance between the plates and their area [1], [17], [18]. Figure 6 represents the main concept of two plate sensors.

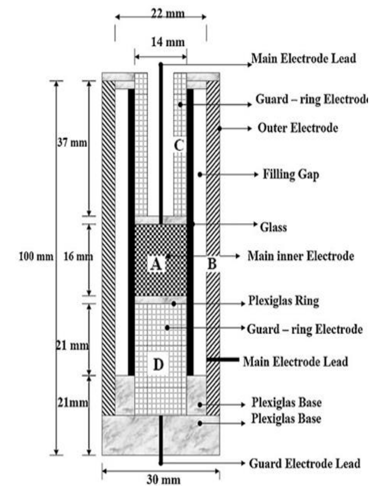

Figure 5. The internal construction of the capacitive electrode [18].

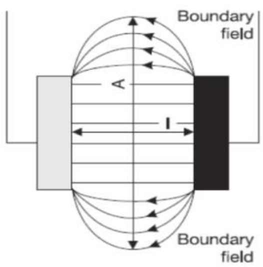

Figure 6. The effect of the potential between the two plates[1].

To design these plates, there are many criteria which must be followed related to the area, size, and distance between the plates. Every type of water has specific range of electrical conductivity. So the electrical conductivity of every kind of water must be measured by specific plates with special properties (Cell constant). Table3 represents the suitable cell constant which must be used for different water kinds.

Table2. Cell constants for every range of conductivity in water kinds [1].

Application Areas	Conductivity Range	Cell Constant
Distillate, Condensate, High-Purity, Fully-Desalinated Water	$\gamma < 10$ μS/cm	$K' \leq 0.1$ cm^{-1}
Ground, Surface and Drinking Water	$\gamma < 10 – 10,000$ μS/cm	$K' \leq 1$ cm^{-1}
Sea Water and Saline Solution	$\gamma > 10$ mS/cm	$K' \leq 10$ cm^{-1}

The inspecting system, designed for this research, measures the quality of drinking water in pipes and walls. So, it was designed with constant cell “K” equal to $1cm^{-1}$ by depending on the information mentioned in table3. The dimensions used to design the plates are as follows:
Plate’s length is 20mm.
Plate’s width is 20mm.
The distance between the two plates is 40mm.
Stainless steel material was used to design the two plates. This material doesn’t react with salts [19].

3.3 Electronic system

The electronic system measures salt concentration and electrical conductivity. And also controls all the system. This subsystem allows the user to interact with the system. The main parts of this subsystem are summarized in Figure 7. Firstly, the Alternative voltage generation circuit which is used to generate the required signal to activate the water without polarization as shown in Figure 8. Secondly, the Ac measuring circuit which is used to measure the signal between the two plates in the designed sensor as shown in Figure 9. This signal is generated according to salts concentration. Finally, the control circuit contains the main controller with software representing the proposed working algorithm, and the interfacing components such as LCD and Keypad. This circuit allows the operator to obtain register data inside the system.

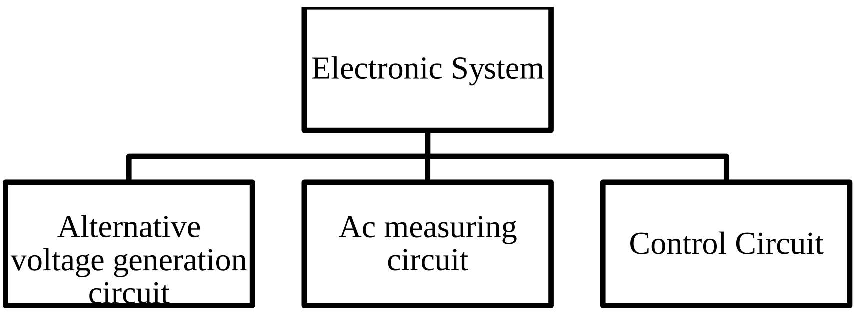

Figure 7. Main parts of the electronic system.

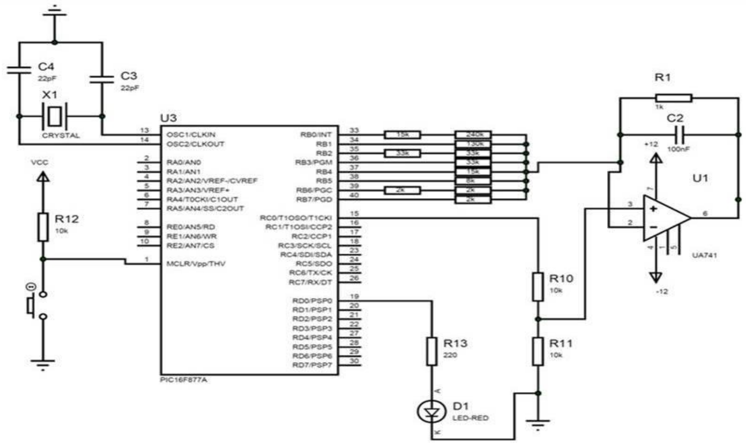

Figure 8. AC voltage generation circuit.

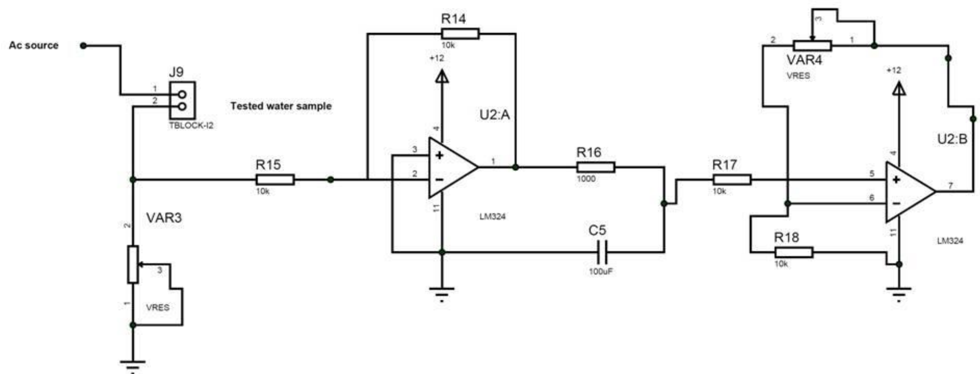

Figure 9. Electrical current to voltage converter.

4. Results and Discussion

The system components were manufactured, the main cone was modelled using SolidWorks software as shown in Figure 10, Figure 11 illustrates the system after manufacturing.

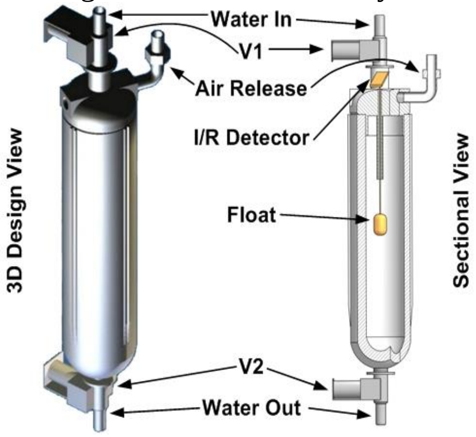

Figure 10. The design and the construction of electromechanical testing container.

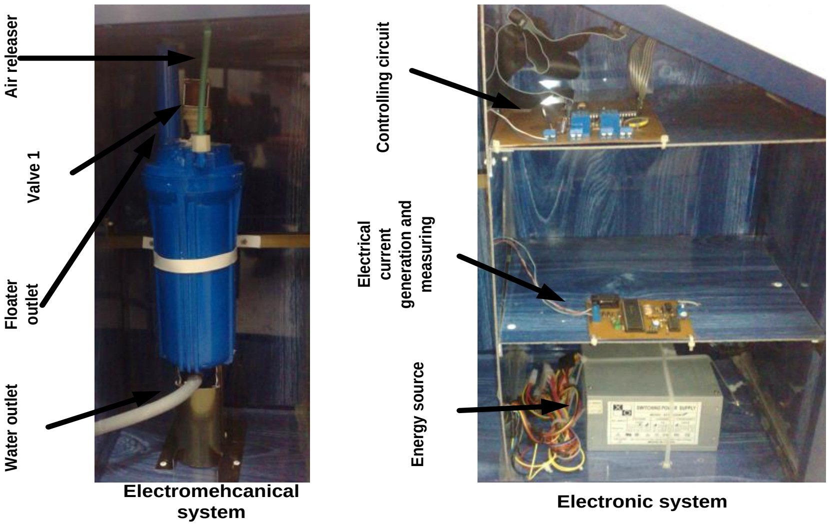

Figure 11. The real components of IWQMS.

Many experiments were performed on this system by changing the water conductivity. Amounts of Sodium Chloride were mixed with distant water to arrive with determined concentration of salts. After that, inspection and measuring of these samples is perofmed twice, one by the standard laboratory device and another by IWQMS, and this is to measure the system accuracy and efficiency. In one of the experiments performed, distant water was mixed with Sodium Chloride (35mg/l) to make calibration. The calibration to the system was done by changing a variable resistance in the measuring circuit, and measuring by laboratory device to reach the minimum error. The minimum value of the variable resistance which produces the minimum error was (40kΩ). After the variable resistance had been fixed at value (40kΩ), the system was used to perform many experiments on water samples with different salt concentration. Table3 includes the results of the performed experiments. The water range was used in this experiment is for underground and drinking water. The sensor was made especially for this range based on the criteria in Table1.

Table 3. The results after system adjustment to measure at concentration (35mg/l).

Salt Conc. (mg/l)	VRs1	VRs2	VRs3	Averag e VRs	Current through Water (μA)	Voltage across Water (V)	EC–Lab Device (μS/cm)	EC–IWQMS (μS/cm)	Pure Error	% Error
15	2.23	2.59	2.55	2.46	61.4	0.573	56.0	107.1	-51.1	-91.3
20	2.20	2.20	2.19	2.20	54.9	0.833	54.0	65.9	-11.9	-22.0
25	2.22	2.22	2.22	2.22	55.5	0.810	63.0	68.5	-5.5	-8.8
30	2.26	2.26	2.26	2.26	56.5	0.770	75.0	73.4	1.6	2.2
35*	**2.37**	**2.37**	**2.37**	**2.37**	**59.3**	**0.660**	**90.0**	**89.8**	**0.2**	**0.3**
40	2.40	2.40	2.40	2.40	60.0	0.630	96.0	95.2	0.8	0.8
45	2.45	2.45	2.45	2.45	61.3	0.580	104.0	105.6	-1.6	-1.5
50	2.44	2.44	2.44	2.44	61.0	0.590	119.0	103.4	15.6	13.1
55	2.48	2.48	2.48	2.48	62.0	0.550	121.0	112.7	8.3	6.8
60	2.53	2.53	2.53	2.53	63.3	0.500	140.0	126.5	13.5	9.6

To reduce the experiment's errors, the mid-range of three readings of electrical voltage on the variable resistance was considered to calculate the electrical voltage and the current in the water sample. The readings (VRs1, VRs2, and VRs3) are represented in Table3. The electrical conductivity of the water was calculated in the microcontroller by implementing equations from 1 to 4. Figure12 represents the comparison between the results of the system measurements and the standard device measurements of the water sample in Table3. The values of the electrical conductivity which were found by this experiment fill in the range of the values of the electrical conductivity of the water kind which is represented in Table2. These results prove that the sensor which was designed is suitable for use in this range.

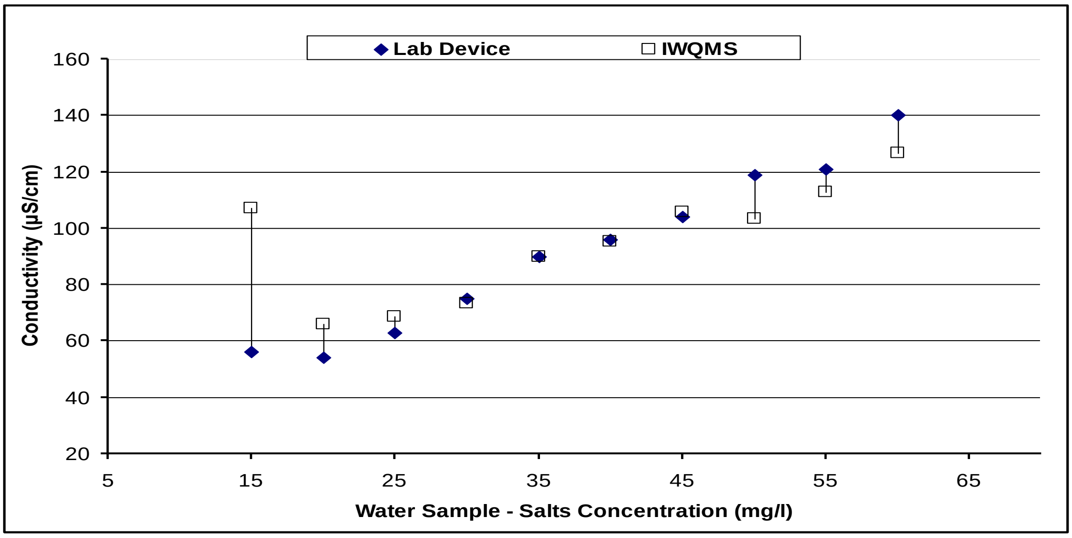

Figure 12. Comparison between the system results and the standard device results after the system adjustment at salt concentration (35mg/l).

These results prove that the system can work with error close to 0.25%. It's clear that the measurement error increases when salt concentration increases up to the value which the system was calibrated on. So that, the system can accurately measure the electrical conductivity in the range ($\pm 10 mg/l$) around the calibrated point. This result has advantage and disadvantage at the same time. The advantage is that the system measures the electrical conductivity with accuracy close the standard device accuracy in the calibration range. The disadvantage is in the variable resistance which the user must calibrate to measure different water samples in different electrical conductivity range. This real and expected phenomenon depends on the physical phenomenon which leads to the electrical conductivity of the water. This is the main reason of the sensor calibration to every sample of water. Another extra experiment was performed to insure the system ability to measure more comprehensive values, random sample of water was picked from the lab and tested. The result by the labor device was 1.9 ms/cm. After the variable resistance (VAR3) had been calibrated at the value $900\,\Omega$, the result was equal to the result of the standard device 1.9ms/cm. and this confirms that the system can be developed to measure different water samples but by using auto calibrated resistance.

5. Conclusion

This research is to design an automated system able to observe the water quality automatically and save the measured data for the future or send it to professionals in the main observation station. It includes three main parts mechanical, electronic and software. The mechanical part is to collet water samples to be inspected, and this part was developed especially to be connected in the pipes. The electronic part is a real time embedded system using PIC Microcontroller 24 series. The main component of the electronic part is the sensor which was developed using two conducting plates. The model of IWQMS system works with accuracy close to the accuracy of standard devices, and is based on calibration to be used in different ranges of water, and this is useful for some applications where the water has to be checked and make a decision to pass or stop, such as food manufacturing system. Many improvements can be made to this system to make an efficient system that can be used in a lot of application as follows:

1- Change the size of the inspection cone to fit for more other applications.
2- Design programmable variable resistor to change the ranges of inspected water.
3- Add a communication system for this device to be used in wide spread application.

Acknowledgements
Acknowledgements for the first place and the first team started working on this project, Alazhar University-Gaza, Dr. Adnan Aish, Bakr Alwawi, Anees Abuhamad.

References

1. Reinhard Manns and Jürgen Schleicher, Information on Conductivity Measurement, 3rd edition, Fulda: JUMO GmbH & Co. KG, 2004.
2. Keener, L.A.R.R.Y., 2001. Water: ensuring its safety for use in food processing operations. Food Saf. Mag, 7, pp.22-25.
3. United Nations Children's Fund, UNICEF Handbook on Water Quality, New York, 2008, Downloadable from: http://www.unicef.org/wes.
4. Riquelme, J.L., Soto, F., Suardíaz, J., Sánchez, P., Iborra, A. and Vera, J.A., 2009. Wireless sensor networks for precision horticulture in Southern Spain. Computers and Electronics in Agriculture, 68(1), pp.25-35.
5. Kupperman, R.H. and Trent, D.M., 1979. Terrorism: Threat, reality, response (Vol. 204). Stanford, CA: Hoover Institution Press.
6. Raich, J., 2013. Review of sensors to monitor water quality. European Reference Network for Critical Infrastructure Protection (ERNCIP) project.
7. Tuna, G., Arkoc, O. and Gulez, K., 2013. Continuous monitoring of water quality using portable and low-cost approaches. International Journal of Distributed Sensor Networks.
8. Wang, J., Zhu, L., Daut, G., Ju, J., Lin, X., Wang, Y. and Zhen, X., 2009. Investigation of bathymetry and water quality of Lake Nam Co, the largest lake on the central Tibetan Plateau, China. Limnology, 10(2), pp.149-158.
9. Wilcock, R.J., Monaghan, R.M., Quinn, J.M., Campbell, A.M., Thorrold, B.S., Duncan, M.J., McGowan, A.W. and Betteridge, K., 2006. Land-use impacts and water quality targets in the intensive dairying catchment of the Toenepi Stream, New Zealand. New Zealand Journal of Marine and Freshwater Research, 40(1), pp.123-140.
10. Glasgow, H.B., Burkholder, J.M., Reed, R.E., Lewitus, A.J. and Kleinman, J.E., 2004. Real-time remote monitoring of water quality: a review of current applications, and advancements in sensor, telemetry, and computing technologies. Journal of Experimental Marine Biology and Ecology, 300(1), pp.409-448.
11. Glasgow, H.B., Burkholder, J.M., Reed, R.E., Lewitus, A.J. and Kleinman, J.E., 2004. Real-time remote monitoring of water quality: a review of current applications, and advancements in sensor, telemetry, and computing technologies. Journal of Experimental Marine Biology and Ecology, 300(1), pp.409-448.
12. Barabde, M. and Danve, S., 2015. Real time water quality monitoring system. Int. J. Innov. Res. Comp. Comm. Eng, 3(6).
13. Dong, J., Wang, G., Yan, H., Xu, J. and Zhang, X., 2015. A survey of smart water quality monitoring system. Environmental Science and Pollution Research, 22(7), pp.4893-4906.
14. Claude E .Boyed ,Water Quality: An Introduction, 1st edition, Springer, 2000, ISBN: 0792378539.
15. Glasgow, H.B., Burkholder, J.M., Reed, R.E., Lewitus, A.J. and Kleinman, J.E., 2004. Real-time remote monitoring of water quality: a review of current applications, and advancements in sensor, telemetry, and computing technologies. Journal of Experimental Marine Biology and Ecology, 300(1), pp.409-448.
16. H. Golnabi, Measurements of the Electrical Parameters for Different Water samples, Measurement, Volume 44, Issue 10, December 2011, pp. 2175 – 2184.
17. Allen J. Brad and Larry R. Faulkner, Electrochemical Methods: Fundamentals and Applications, 2nd edition, Wiley, 2001, ISBN: 978-0-471-04372-0.
18. Nicholson, R. S. and Irving. Shain, Theory of Stationary Electrode Polarography: Single Scan and Cyclic Methods Applied to Reversible, Irreversible, and Kinetic Systems, Analytical Chemistry, Volume 36, Issue 4, April 1964, pp. 706 – 723.
19. Michael F. Ashby and David R. H. Jones, An Introduction to Microstructures, Processing and Design, Second Edition, OXFORD, ISBN: 0 7506 4019 7
20. John Bird, Electrical Circuit Theory and Technology, 2nd revised edition, Newnes, Oxford, 2003, ISBN: 0750657847.