Real-time water quality system in internet of things

M Cho Zin¹, G Lenin¹, L Huo Chong¹, Prassana MV²

¹ Department of Electrical and Computer Engineering, Faculty of Engineering and Science, Curtin University, CDT 250. 98009 Miri, Sarawak, Malaysia.
² Department of Applied Geology, Faculty of Engineering and Science, Curtin University, CDT 250. 98009 Miri, Sarawak, Malaysia.

Email: cho.zin.myint@postgrad.curtin.edu.my

Abstract. Wireless Sensor Network (WSN) in Internet of Thing (IoT) is used in different areas of research for monitoring, collecting and analysing data from remote sites. This paper presents a WSN based reconfigurable interface device for water quality monitoring (WQM) in an IoT environment. The proposed WQM system consists of sensors, Field Programmable Gate Array (FPGA), Zigbee wireless communication protocol and personal computer. The system is designed for monitoring water quality such as water temperature, water level, water pH, turbidity of water and Carbon dioxide on the surface of water. The FPGA board is the heart of the system and a Very High Speed Integrated Circuit Hardware Description Language and C++ are used for software system of the proposed designed device. The proposed system collected the data in parallel and in real time basis with high speed from multiple different sensor nodes. The results of the proposed system were validated with the laboratory experiments. Based on the results, it can be concluded that there was no significant difference of water data measurement between the proposed system and the laboratory measurement. The proposed WQM system was able to minimise the operating time, cost and power consumption.

1. Introduction

As the Internet of Things (IoT) involves every aspect of human daily chores nowadays, the applications of IoT bring the potential resolutions in healthcare services, education, smart building, environmental monitoring and additional chapters of modern living. Recently, the environmental monitoring technology has been increasingly important due to the climate change, natural disasters and natural hazards [1-3]. The environmental monitoring application consists of multiple sensors that detect a diversity of Wireless Sensor Network (WSN) sensor data in IoT environments [4]. Therefore, low power consumption and low-cost sensors are important criteria implement in the implementation of WSN in IoT. For environmental monitoring applications, the number of sensors deployed in IoT is the primary factor of high cost for better replacement and servicing. Therefore, the selection of hardware components such as sensors, microprocessor and wireless communication protocol is the priority issue for the implementation of energy-constraint sensor nodes in a remote environment. The system needs to be user friendly, flexible and affordable. Hence, the selection of software is also important. Tiwari [5] presented a smart sensor interface device for Water Quality Monitoring (WQM)
based on a hardware/software. The Complex Programmable Logic Device (CPLD) is used as the core controller. The proposed system detects the water parameters such as light intensity, water temperature, CO\textsubscript{2}, and turbidity. Chi et al. [6] designed an industrial WSN system based on the IEEE 1451 standard to detect the quality of water. The system consists of a reconfigurable smart sensor interface device using the combination of CPLD and wireless communication module. The studies done by Karray et al. [7] showed that WQM system based on Field Programmable Gate Array (FPGA) provides energy efficiency in shorter time due to parallel processing. Hsia [8] designed a water meter system and leakage detection based on an FPGA processor. The system comprises a signal generator, a detection circuit, and FPGA which comprehends the data encoder and a serial port for the data transmission. Postolache et al. [9, 10] designed a WQM system using water quality sensors to detect turbidity, pH, conductivity, and a compact reconfigurable I/O (RIO) real-time embedded controller and an FPGA.

However, the existing systems of FPGA-based WQM do not provide a complete incorporation and self-sufficiency to wireless sensor nodes. Further study is therefore necessary to achieve higher performance efficiency of the designed devices in the development of WSN in the IoT environment. In the proposed study, the data of five water parameters such as water level, water temperature, water properties (or) pH of water, concentration of CO\textsubscript{2} on the water surface, and the turbidity of water in real-time basis are monitored by the water parameter sensors. The detected water parameters data is transmitted to the FPGA board to compute and execute the process of wireless transmission. The computed data is transmitted to the control station through ZigBee wireless communication module. Hence, the users from a remote site can monitor real-time data of water quality through their monitoring Personal Computer (PC).

2. System design
The design of the WQM system consists of hardware and software.

2.1. Hardware component
The design of the real-time WSN system for WQM in IoT environment comprises the core hardware components such as sensors, FPGA Board, Wireless Transmitter Unit (Fig.1) and Wireless Receiver Unit. The components for the proposed system are designed using Nios-II soft-core processor in Qsys Tools of Quartus II. The complete design is downloaded to the FPGA SoC board.

2.2. Software component
In the proposed system, the Altera Quartus II Software is the major FPGA development tool. The C codes running over the embedded Nios II processor within the FPGA processor and Very High Integrated Circuit Hardware Description Language (VHDL) codes are used to operate the transmitter unit. The calculations of water parameters data and commands of wireless transceiver modules are programmed in Nios II Eclipse using VHDL and C. The software program is compiled and downloaded to FPGA board using Quartus II software. To display the water parameter data, the Grafana software is utilised to view time series data. The Grafana provides easy installation on the monitoring PC operated in the Linux Operating System.

2.3. Implementing hardware components on FPGA board
The hardware components such as XBee transceiver modules and sensors are implemented on the FPGA board. The output power of 60 mW and two XBee-Pro modules are installed in the proposed design to achieve a longer range. The transmitter module of XBee Pro S1 is interfaced to the I/O port of FPGA. The voltage regulator converts from 5V to 3.3V to supply power to XBee Pro S1. 4 pins of XBee Pro S1 transmitter module are used to connect to FPGA board; Pin 1 to Vcc (+3.3 V), Pin 2 to TX, Pin 3 to Rx and Pin 4 to GND(0 V) respectively. To connect FPGA and the temperature sensor 1-Wire Digital Thermometer DS18B20, only one wire is connected. The sensor DS18B20 is connected
to FPGA board using PS/2 female connector port using 6-pin Mini-DIN PS/2 male connector cable. 5V power is provided by PS/2 connector. The connector comprises pins for ground, +5V, serial data, and serial clock. For connecting the two 1-wire lines of DS18B20, Data and Clock pins of the PS/2 connector are used. 2kΩ pull-up resistor is needed to prevent damage to the hardware and software. The transducer controller executes the commands to trigger the sensor.
The Ultrasonic sensor LV-MAXSONAR-EZ1 is interfaced with RS232 line is achieved by the default state UART mode. The LV-MAXSONAR-EZ1 ultrasonic sensor collects the range data by three individual modes such as analog voltage mode, pulse width mode, and RS232 serial mode. From the FPGA board, GPIO 1 D1 is connected to the Tx of the sensor and GPIO 1 D5 of FPGA is connected to Rx. FPGA GPIO 1 which is 5V power pin is connected with Vcc pin of the LV-MaxSonar-EZ1 sensor. FPGA GPIO 1 ground pin is connected to the ND pin of LV-MaxSonar-EZ1. Since the CO₂ Sensor SKU: SEN0219 is an analogue sensor, the built-in Analogue to Digital Converter (ADC) AD7928 of FPGA is used for converting the analogue output to digital. There are ten pins such as a +5V pin, (+), a 0V pin (-), and eight analogue channels (0-7) on ADC pin header. The Vcc (4.5 – 5.5V), GND, and signal pin which provides the analogue output (0.4 – 2V) are integrated. The Vcc pin of CO₂ sensor is connected to pin 29 of GPIO 0 (JP1) which is the power source of FPGA. The GND pin of CO₂ sensor is connected to the pin 30 GND of GPIO 0 (JP1) of FPGA via power array respectively.

The SPI ADC and the signal interface of the CO₂ sensor are implemented in Qsys. Since the analogue output (0V – 4.5V) of turbidity sensor SKE: SEN0189 is used in the proposed system, the ADC AD7928 is used to achieve digital voltage output. The Vcc of turbidity sensor is connected to the FPGA pin 29 of GPIO 0 (JP1) which is power source and the GND pin of turbidity sensor is connected to the pin 30 of GPIO 0 (JP1) GND of FPGA respectively via power array. The Logic utilization (in ALMs) of 1,724 / 32,070 (5%), the total registers of 2662, total pins of 149 / 457 (33 %), total block memory bits of 83,072 / 4,065,280 (2 %), total PLLs of 1 / 6 (17 %) and maximum Clock Frequency of 58.75 MHz are used as the total resource utilisation to design the FPGA board of the proposed real-time WQM system in IoT.

3. Experimental measurement

The quality of lake surface water was measured from Curtin Lake which is located in Curtin University, Sarawak campus, Miri, northern Sarawak in the Borneo Island. The study site latitudes 4° 30’ 50.112” N and longitudes 114° 0’ 58.0248” E is located 18 m above the sea level. The sensor interfaced DE-1 SoC FPGA board (Fig.2) is placed at the bank of the lake to measure the physical parameters of water in the morning and evening time. The pH sensor probe, turbidity sensor and temperature sensor are placed in the lake water and CO₂ sensor is positioned 5cm above the water surface. To measure the distance from the water surface level to the ground level of the lake bank, the LV-MAXSONAR-EZ1 sensor is placed at the same level with the ground. The XBee Pro receiver is placed 86 m far away from the XBee Pro transmitter unit which is interfaced with FPGA. When the sensor interfaced FPGA board is switched on, the sensors are initiated to detect the relevant parameter of water data. Then, the detected water data is transmitted wirelessly to the observing PC which is 86 m away from the sensor interfaced FPGA. The water quality is monitored at the same site twice a day for fifteen (15) consecutive days. The time interval between each sample of water quality is 5s since the default of the system is set in continuous mode and the data is refreshed every 5s. A total of 2537 water data are collected in 15 days. The system is powered by 12 V direct line of electricity or the maximum 6 hours of operating time is achieved by rechargeable Lithium Polymer battery of 6000 mAh.

4. Experimental result

In Fig. 4, the results of collected water are shown in the console window of LiClipse. The temperature of water “T” is shown in degree Celsius, the distance between the sensor placed at the same level with lake bank and the water surface “D” is shown in millimeter, the turbidity of water “U” is shown in output voltage, the CO₂ above the water surface “C” is shown in ppm, and the pH value “P” is shown in 2 decimal values. The descriptive analysis of measured water quality is presented in Table 1. The pH value is collected were in the range of 5.56 – 6.78 hydrogen ions. The pH values of the lake water
samples collected in the morning were in the range of 5.56 – 6.78 hydrogen ions, whereas the pH values were measured from 5.25 to 6.22 hydrogen ions in the evening.

**Table 1.** Descriptive analysis of water quality

| Parameter      | Range   | Maximum | Minimum | Mean   |
|----------------|---------|---------|---------|--------|
| Temperature (ºC) | 4.625   | 33.8125 | 29.1875 | 31.5   |
| Distance (m)   | 0.381   | 0.635   | 0.254   | 0.445  |
| Turbidity (NTU) | 5<50<500 | <500    | >5      | <500>50 |
| CO2 (ppm)      | 1127    | 1656    | 529     | 1092.5 |
| pH             | 1.779   | 7.02    | 5.241   | 6.1305 |

**Table 2.** Comparison between laboratory measurement and designed device measurement

| Parameter (Mean) | Laboratory | Device |
|------------------|------------|--------|
| Temperature (ºC) | 30.77      | 30.92  |
| pH               | 6.3        | 5.91   |
From all collected 2537 data in 15 days, the lowest pH value 5.241 was measured at 5:00 pm on 21 April, and the highest pH value 7.02 was measured at 7:30 am on 26 April. The range of 642.08 ppm and 898.5 ppm of CO$_2$ were measured in the morning, and the range of 645.4 ppm and 898.5 ppm were measured in the evening. 529 ppm was measured as the lowest CO$_2$ value and 1656 ppm was measured as the highest CO$_2$ value. The output of turbidity sensor is in voltage which is estimated in NTU. The turbidity of the Lake water in the morning was measured in the range of less than 0.5 NTU to greater than 500 NTU. The mean value of turbidity was in the range of less than 500 NTU and greater than 50 NTU. Therefore, the turbidity of the water was between 50 NTU and 500 NTU. The distance from the water surface to the ground level of Lake Bank was measured in the range of 0.292 m and 0.559 m in the morning, and 0.254 m and 0.61 m in the evening. 0.254 m was measured as the lowest distance and 0.635 m was measured as the highest distance at 7:30 am on 25 April. 200 cases of random data are selected to analyse in Statistical Package for the Social Science (SPSS) Version 20 for the correlation of temperature, CO$_2$, and pH since the water data does not change significantly. The temperature is divided by 10 and the pH is divided by 6 for no significant difference in one hour. The correlation between the temperature and pH is negative and significant at 0.01 level (two-tailed). The correlation between the CO$_2$ and pH is negative and significant at 0.01 level (two-tailed). The correlation between the CO$_2$ and pH is negative and significant at 0.01 level (two-tailed). The value of pH measured by the system is compared and verified with the laboratory experiment. The mean value of pH and temperature is compared with the laboratory measurements. The temperature difference between the laboratory measurement and the designed device was found to be 0.15. The difference for pH was found to be 0.4. Therefore, it can be concluded that the system has achieved the correct result of water data measurement.

5. Conclusion and future work
Wireless real-time WQM system in IoT has been designed and implemented to measure five water parameters. The system achieves high execution speed as the water data is detected within 1 or 2 minutes after the switched is on and the system executes parallel processing. The proposed system exceeds the performance of the existing microcontrollers-based WSN design by utilising the FPGA SoC board. The experimental results of the proposed design offer reliable outcomes which are low-cost, low power consumption, strong communication ability, and reliable real-time measurement. The current system can be additionally upgraded by integrating additional sensors for a broader measuring area.

References
[1] A. Zanella, N. Bui, A. Castellani, L. Vangelista and M. Zorzi, “Internet of Things for Smart Cities,” in IEEE Internet of Things Journal, vol. 1, no. 1, pp. 22-32, Feb. 2014.
[2] D. Miorandi, S. Sicari, F. De Pellegrini and I. Chlamtac, “Internet of things: vision, applications and research challenges,” Ad hoc Networks, Sept. 30, 2012, vol. 10, no. 7, pp. 1497–1516.
[3] M. T. Lazarescu, “Design of a WSN Platform for Long-Term Environmental Monitoring for IoT Applications,” in IEEE Journal on Emerging and Selected Topics in Circuits and Systems, vol. 3, no. 1, pp. 45–54, March 2013.
[4] F. Salvadori et al., “Monitoring in Industrial Systems Using Wireless Sensor Network with Dynamic Power Management,” in IEEE Transactions on Instrumentation and Measurement, vol. 58, no. 9, pp. 3104–3111, Sept. 2009.
[5] G. Tiwari, “Hardware/Software Based a Smart Sensor Interface Device for Water Quality Monitoring in IoT Environment”, International Journal of Technology and Science, vol. 3, issue. 1, pp. 5–9, 2014.
[6] Q. Chi, H. Yan, C. Zhang, Z. Pang and L. D. Xu, “A Reconfigurable Smart Sensor Interface for
Industrial WSN in IoT Environment,” in *IEEE Transactions on Industrial Informatics*, vol. 10, no. 2, pp. 1417-1425, May 2014.

[7] F. Karray, M. Wassim, M. Abid, D. Houssaini, A. M. Obeid, S. M. Qasim, M. S. Saleh, “Architecture of Wireless Sensor Nodes for Water Monitoring Applications: From Microcontroller-based System to SoC Solutions,” in *20th IMEKO TC4 International Symposium*, 15–17 Sept. 2014.

[8] S. C. Hsia, S. W. Hsu and Y. J. Chang, “Remote monitoring and smart sensing for water meter system and leakage detection,” in *IET Wireless Sensor Systems*, vol. 2, no. 4, pp. 402–408, Dec. 2012.

[9] O. Postolache, P. S. Gir˘ao, J. M. Pereira and H. Ramos, “Water quality sensors calibration system based on reconfigurable FPGA technology,” in *Proc. of XVIII IMEKO World Congress*, pp. 1–5, Sept. 2006.

[10] O. Postolache, J. M. D. Pereira, P. S. Gir˘ao, “Real-time sensing channel modelling based on an FPGA and real-time controller,” in *Proc. of Instrument and Measurement Technology Conference (IMTC)*, pp. 557– 562, April 2006.