In Real Time Reconfigurable Internet of Things (Iot) Smart Water Quality Monitoring System

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Abstract- *Efficient system and the effective of water quality monitoring (WQM) are critical implementation for the issue of polluted water globally, with increasing in the development of Wireless Sensor Network (WSN) technology in the Internet of Things (IoT) environment, real time water quality monitoring is remotely monitored by means of real-time data acquisition, transmission and processing. This paper presents a reconfigurable smart sensor interface device for water quality monitoring system in an IoT environment. The smart WQM system consists of Field Programmable Gate Array (FPGA) design board, sensors; ZigBee based wireless communication module and personal computer (PC). The FPGA board is the core component of the proposed system and it is programmed in very high speed integrated circuit hardware description language (VHDL) and C programming language using Quartus II software and Qsys tool. The proposed WQM system collects the five parameters of water data such as water pH, water level, turbidity, carbon dioxide (CO_2) on the surface of water and water temperature in parallel and in real time basis with high speed from multiple different sensor nodes.*

Keywords- Very large scale Integration (VLSI), Internet of Things (IoT); smart; Wireless Sensor Network (WSN); water parameters; ZigBee.

I. INTRODUCTION

Wireless communication technologies and the Wireless Sensor Network (WSN) [1] have been increasingly developed for assisting human's personal and professional daily tasks. The applications of wireless technologies have been developed for the data acquisition, building control, environmental monitoring systems and automation of manufacturing processes in recent years. Today's state-of-the-art WSNs have more advantages such as low costs for both installation and maintenance, and longer operating time. The remote sensor network can be used for stationary or mobile sensor networks. The remote sensor network is commonly used for different purposes such as surveying the development of city infrastructure, environmental monitoring, telemedicine or remote health care, research in agriculture, fishing surveillance, farming, border security, traffic management, forestry management, and disaster prevention [2]. A WSN

consists of compactly dispersed sensor nodes for sensing, signal processing, embedded computing, and connectivity [3]. This system enables the interaction between persons or computers and the surrounding environment through wireless link [4]. Although the WSNs were used in military and heavy industrial applications originally, today's WSN applications are used for different purposes from the light industrial to heavy industrial systems. The WSN system allows users to monitor and control the connected devices from the base station through different wireless communication standards such as Wi-Fi, General Packet Radio Service (GPRS), Bluetooth, ZigBee, Radio Frequency Identification (RFID), and cellular technologies [5]. The users can monitor the data through a wireless network which can be designed based on one of those wireless communication standards. The advantages of WSN are low power consumption, redundant data acquisition, remote monitoring, fast network establishment, wide coverage area, and high monitoring precision and low duty cycle. Thus, the WSN to the real world is practically unlimited from physical security, environmental monitoring and climate changes, positioning and tracking and health care to logistic, localization, and so on [6]. The Internet of Things (IoT) was developed in parallel to WSNs and is a physical network which connects all things in order to exchange the data and information through the data sensing devices such as sensors, actuators and computers in line with relevant protocols. In other word, many things are connected into networks in one form or another. The aims of intelligent, identifying, monitoring, locating, tracking and controlling things are achieved by IoTs [7]. There is a variety of IoT applications such as RFID tags, sensor technology, mobile technology and other smart technologies [8]. The integration of inexpensive and low powered sensors into IoT is a major evolution of WSNs [9].
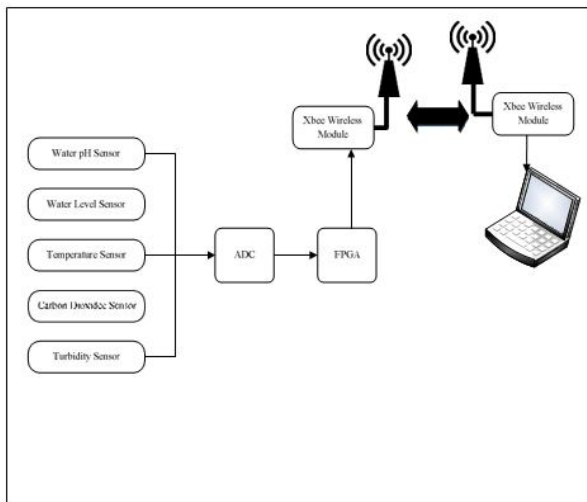
Figure 1: The block diagram of smart water quality monitoring system

The WSN in IoT applications enables the information and communication systems invisibly embedded in the environment since the sensor network enables people to interact with the real world remotely [10]. Recently, an environmental monitoring system based on WSN system using different wireless communication standards has attracted intensive interest. Jing [11] designed a wireless remote monitoring system for water supply based on GPRS using PIC microcontroller. The PC management software is developed using VC++6.0 software platform. Purohit and Gokhale [12] designed a real-time water quality measurement system using Intel microcontroller, Global System for Mobile communications (GSM) module, assorted water quality measuring sensors, Analogue to Digital Converter (ADC), and a liquid crystal display (LCD). Since microcontrollers have more complex architecture, the development time and cost increase due to the complexity of the circuit design. Beri [13] designed an autonomous real-time device to measure the physical and chemical parameters of water such as pH, temperature and turbidity using Arduino Atmega microcontroller and Zigbee wireless module. Hsia [14] developed a water meter system and leakage detection based on Field Programmable Gate Array (FPGA) chip to realize a signal generator, a detection circuit, data encoder and a serial port for the transmission of data. The proposed system consists of pressure sensor, an ADC and FPGA design board. Chi et al.[15]presented a reconfigurable smart sensor interface device for industrial area of WSN in the IoT environment. These interface devices are restricted as they are commonly based on the comparatively complex dedicated electronic boards [16- 18]. Vijayakumar and Ramya [19] designed a real-time water quality monitoring system in IoT environment. The system consists of several sensors to measure water parameters and the raspberry PI B+ model as a core controller.

For WSN environmental monitoring application, the energy consumption is a critical issue due to the deployment of a WSN based on the IEEE 1451 standard by combining with Complex Programmable Logic Device (CPLD) and the application of wireless communication in IoT environment. The research should be performed to achieve a broad space for development in the large number of energy-constrained sensor nodes in an unattended environment. Therefore, a low-power, low-cost single-chip fully integrated autonomous System On-Chip (SoC) based wireless sensor node is required to solve these problems. In the proposed smart WQM system, the water quality monitoring system consists of a group of sensors to monitor the water parameters such as water level, water temperature, carbon dioxide (CO_2) on the surface of water, turbidity of water and water pH value. Firstly, the sensors detect the water parameters, and then the data is computed on Altera DE1-SoC board using Very High Speed Integrated Circuit Hardware Description Language (VHDL) programming language and C codes. Afterwards, the computed data is transmitted wirelessly to the base station where the user can monitor the water parameters through ZigBee wireless communication module. The block diagram of smart WQM system is shown in Fig. 1.

II. HARDWARE COMPONENTS

In the proposed smart WQM system, a reconfigurable smart sensor interface device that integrates data collection, data processing, and wireless transmission is designed. The hardware experimental set-up of smart WQM system is shown in Fig.2. The hardware of wireless water quality monitoring system comprises the following components:

- Ultrasonic Sensor
- pH Sensor
- Digital Thermometer Sensor
- Turbidity Sensor
- CO_2 Sensor
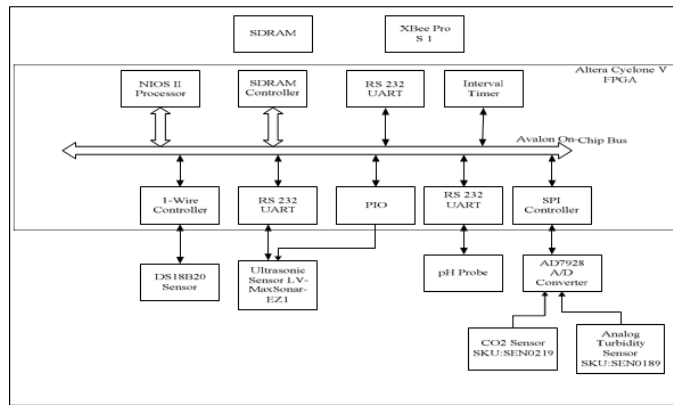- Radio Frequency (RF) Module
- FPGA Board

Figure 2: The system block diagram of smart water quality monitoring system

A. Ultrasonic Sensor

In the proposed smart WQM system, the ultrasonic sensor (LV-MaxSonar-EZ1) is chosen to monitor the water level. This ultrasonic sensor is operated by emitting high-frequency sonic wave at regular time interval starting from the front of the transducer. The sonic waves are reflected by an object and received back in the transducer. The time interval between emitting and receiving sound waves is proportional to the distance between the transducer and the object can be calculated. As the ultrasonic sensor is using sound wave instead of light wave, it is more suitable for sensing uneven surface such as water surface. According to its datasheet, the ultrasonic sensor detects objects from 0-inches to 254-inches (6.45-meters) and provides sonar range information from 6-inches out to 254-inches with 1-inch resolution.

B. pH Sensor

In the proposed smart WQM system, the Atlas scientific pH kit is used to detect the pH value of water. The pH kit consists of three main components: EZO TM class embedded pH circuit, BNC shield, and pH probe. In the process of collecting water pH data, the pH probe is connected to BNC shield. The BNC shield transfers the pH probe sensing data to the embedded pH circuit, and the resulted pH data is then provided to the FPGA board. The embedded pH circuit can be operated in two modes. The pH data is converted into binary by the embedded pH such as UART mode and I2C mode. In this proposed smart WQM system, the UART mode is used for its default mode with baud rate of 9600 bps, 8 data bits, 1 stop bit, no parity and no flow control.

C. Digital Thermometer Sensor

In the proposed smart WQM system, the temperature of the water is monitored using a 1-wire protocol digital thermometer sensor (DS18B20). The DS18B20 temperature sensor provides 9-bit to 12-bit Celsius degree temperature measurements. The DS18B20 is powered from the data line.

The range of power supply 3.0V to 5.5V from data line is needed to power the DS18B20. The accuracy of DS18B20 is $\pm0.5°C$ from -10°C to +85°C. The temperature is converted 12-bit digital word in a maximum of 750 milliseconds. The temperature sensor DS18B20 is connected to the configurable NiosII soft processor system which is implemented on the Cyclone V FPGA of Altera DE1-SoC board.

D. Turbidity Sensor

In the proposed smart WQM system, the turbidity sensor SKU: SEN0189 is used to detect water quality by measuring level of turbidity. The turbidity sensor enables the detection of suspended particles in water by measuring the light transmittance and analogue and digital signal output modes, either of the mode can be selected according to the microcontroller unit (MCU). The threshold is adjustable by adjusting the potentiometer in digital signal mode. The operating voltage of the turbidity sensor is 5V DC and the operating current is 40mA (max) respectively. According to the reference chart for the mapping from the output voltage to the Nephelometric Turbidity Units (NTU) depending on different temperature, when the sensor is left in the pure water, that is NTU < 0.5, the output should be "4.1$\pm$0.3V" when temperature is 10-50< .

E. CO₂ Sensor

In the proposed smart WQM system, the Gravity: Analog Infrared CO_2 sensor SKU: SEN0219 is used to measure the concentration of CO_2. The concentration of CO_2 is measured in parts per million (ppm). One ppm is equivalent to 1 milligram of something per liter of water (mg/l) or1 milligram of something per kilogram soil (mg/kg). The characteristics of SEN0219 are waterproof and anti-corrosion, high sensitivity, low power consumption, stability, temperature compensation, linear output, high life cycle, anti-water vapour interference and no poisoning. The operating voltage is 4.5-5.5V DC and average current is <60 mA at 5V, the peak current: 150mA at 5V respectively. The effective measuring range of CO_2 sensor is 0-5000 ppm. The accuracy of the CO_2 sensor is $\pm$ (50 ppm + 3% reading).

F. RF Module

In the proposed system, protocol based two XBee 802.15.4 RF modules are used to transmit and receive the data

between the monitoring device and FPGA board. The ZigBee-based WSN systems are simple to install, and very easy to upgrade. The XBee 802.15.4 is a registered brand name of ZigBee Standard which is manufactured by Digi International. The XBee802.15.4 RF modules include ZigBee/Mesh topologies, and it can support both 2.4 GHz and 900 MHz frequency. The XBee 802.15.4(IEEE 802.15.4 standard) RF module includes two Embedded-Antenna Module, one XBee USB adapter and one voltage adapter. Since the XBee Series Embedded- Antenna Module pins are not exactly same as the normal pin position, the XBee 5V to 3.3V adapter is required to regulate on a normal breadboard or printed circuit board. The XBee USB adapter performs as a connector between the XBee modules and the monitoring device. The voltage adapter converts the 5V to 3.3V under which the XBee Series Embedded-Antenna Modules is operated. The proper configuration is needed before setting up a wireless communication between the monitoring system and the FPGA board. The two ZigBee Series Embedded-Antenna Modules are the key components to create the wireless communication between the monitoring device and the FPGA board that operates in universal asynchronous receiver/transmitter (UART) mode.

g. FPGA Board

The Altera DE1-SoC board is utilized to control the entire system of the proposed smart WQM system. The DE1-SoC development board includes 85K programmable logic elements, 4,450Kbits embedded memory, 6 fractional phase locked loop (PLLs) and 2 hard memory controllers. For communication, two port USB 2.0 Host, UART to USB (USB Mini-B connector), 10/100/1000 Ethernet, PS/2 mouse/keyboard, IR emitter/receiver, and I2Cmultiplexer are provided. The display of the DE1-SoC board is 24-bit video graphics array (VGA) digital-to-analogue converter (DAC). The power supply of 12V direct current (DC) is needed to power the board.

III. SYSTEM ARCHITECTURE

The system block diagram of smart WQM system is shown in Fig. 3. This architecture is used for the entire system of the Cyclone V DE1-SoC FPGA board due to the significant flexibility to deal with a tradeoff between processing and communication. The sensor nodes are stationed at the bank of the water. The measured data of water parameter are collected by the sensor nodes and sent to FPGA board. The analogue output of CO_2 sensor and Turbidity sensor are digitized by AD7928 Analog to Digital converter. The Ultrasonic sensor and pH sensor are interfaced with RS232 and the default state is UART mode which acts as the transmission (TX) line. The

default baud rate is 9600, 8 bits, no parity, no flow control and one stop bit. The temperature sensor DS18B20 communicates over a 1-wire bus which requires only one data line (and ground) for communication with a microcontroller. Serial Peripheral Interface (SPI) bus is used in embedded system to communicate the microprocessor to off-chip sensors, conversion, memory, and control devices. The architecture of SPI is designed for connecting on-chip processors and peripherals together into a system-on-a-programmable chip (SOPC). When the transmitted data from sensor nodes are received by the gateways, SPI transfers the incoming data through the UART interface to the processor. The SPI controller performs nRF24L01 module initialization, receives and sends packets. The Avalon bus is an interface protocol that is designed to connect on-chip processors and peripherals together into the SOPC. The Avalon bus specifies the port connections between master and slave components, and specifies the timing by which these components communicate. The Nios II processor is connected to its embedded peripherals such as parallel input/output (PIO), SPI, on-chip random access memory (RAM), JTAG UART, Timer, UART (RS232 serial port), synchronous dynamic random access memory (SDRAM) controller by means of the Avalon. The multiple slave devices are attached on the Avalon on-chip bus such as SPI, UART, general purpose input/output (GPIO) and custom logic. The Nios II processor is a general purpose configurable soft core processor and it includes a 32-bit central processing unit (CPU) and a combination of peripherals and memory on a single chip. The configuration of Nios II selected the Nios II/fast in order to provide the most effective performance to the processing unit. The SDRAM synchronizes itself with the timing of the CPU. Therefore, the memory controller identifies the exact clock cycle when the requested data is ready. The UART is used to connect Nios II processor to the Zigbee hardware for wireless transmission.

IV. SOFTWARE DESIGN

Since the Altera Quartus II Software is the primary FPGA development tool, the Altera Quartus II Software and the Nios II Embedded Design Suite (EDS) are chosen to build a hardware system design and create a software program that runs on the Nios II system. This programmable logic device design software is produced by Altera and it is compatible with Altera DE1-SoC design board. To display the wirelessly received data of water parameters on PC, the Pythons codes are used to display on the Grafana. The monitoring PC is operated in Linux mode.

A. Software Program

The software program consists of the C codes running over the embedded Nios II processor within the FPGA processor and VHDL codes. The Quartus II software is used to create VHDL codes of the interfaces, then the compilation is performed and the system is downloaded into the FPGA device. The Nios II is a soft processor and it is implemented in the FPGA device by using the Quartus II CAD system. The Nios II Integrated Development Environment (IDE) is software development environment of Nios II processor and it is based on the GNU C compiler and Eclipse IDE. The Nios II Software Build Tools (SBT) is used for Eclipse™ and all software development tasks are performed in the Nios II processor system. The Nios II system is generated using Qsys to add the desired components, and to configure how the components connect together. The C software application code is created with the Nios II SBT for Eclipse by using information from the **.sopcinfo** file which is needed to configure the FPGA before running and debugging the project on target hardware. The software programs for sensor nodes and wireless network are written in C and it is run in NIOS II IDE with the NIOS II processor. Finally, the Nios II system is integrated into the Quartus II project. Later, the final FPGA hardware design is created by using the Quartus II software.

V. CONCLUSION

The proposed smart WQM system of single chip solution to interface transducers to sensor network using FPGA is presented with wireless method by using a wireless ZigBee module. The results of the five parameters of water quality are verified that the system achieved the reliability and feasibility of using it for the actual monitoring purposes. The water temperature may vary from 0 to 0.4 Degree Celsius depending on the speed of the ambient air temperature cycles. The time interval of monitoring can be changed depending on the need. By introducing the FPGA board, the proposed system inherits high execution speed and reusable Intellectual Property (IP) design. The proposed system will assist in protecting the ecological environment of water resources. The smart WQM system minimizes the time and costs in detecting water quality of a reservoir as part of the environmental management. The WSN network will be developed in the future comprising of more number of nodes to extend the coverage range.

VI. ACKNOWLEDGEMENT

REFERENCES

[1] Li,S.; Xu,L.; Wang,X.; Wang,J., "Integration of Hybrid Wireless Networks in Cloud Services Oriented Enterprise Information Systems," *Enterp. Inf. Syst.*, vol. 6, no. 2, pp. 165–187, 2012.

[2] Akyildiz,I,F.;Su,W.; Sankarasubramaniam,Y.; Cayirci,Y., "Wireless Sensor Networks: A Survey", *Computer Networks*, vol.38, pp. 393–422, 2002.

[3] W. R. Heinzelman et al., ''Adaptive Protocols for Information Dissemination in Wireless Sensor Networks,'' Proceedings of the 5th ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom'99), Seattle, WA, Aug. 1999, pp. 174-185.

[4] Broring, A. et al., "New Generation Sensor Web Enablement" Sensors, vol.11, 2011, pp. 2652-2699. ISSN 1424-8220. Available at doi:10.3390/s110302652

[5] Sharma,H and Sharma,S., "A Review of Sensor Networks: Technologies and Applications", in *Engineering and Computational Sciences (RAECS), 2014 Recent Advances in*, Chandigarh, pp.1–4, 2014.

[6] Buratti, C.; Conti, A.; Dardari, D.; and Verdone, R.,Verdone, R., "An Overview on Wireless Sensor Networks Technology and Evolution", *Sensors* 2009, vol.*9*, pp.6869-6896

[7] J. A. Stankovic, "Research directions for the Internet of Things," *IEEE Internet Things J.*, vol. 1, no. 1, pp. 3–9, Feb. 2014

[8] Peris-Ortiz, M.; Bennett, D.; Yábar, D. P., "Sustainable Smart Cities: Creating Spaces for Technological, Social and Business Development", Springer, 5 October 2016, p.103

[9] IEC International Electrotechnical Commission, "Wireless Sensor Networks", White Paper, July 31 2014, p.13

[10] Chen *et al.*, "A Vision of IoT: Applications, Challenges, and Opportunities With China Perspective", IEEE Internet of Things Journal, vol.1, No.4, Aug 2014.

[11] Jing,M., "The Design of Wireless Remote Monitoring System of Water Supply Based on GPRS", *Computer Science and Society (ISCCS), 2011 International Symposium on*, Kota Kinabalu, 2011, pp. 29-31.

[12] Purohit,A and Gokhale,U., "Real Time Water Quality Measurement System based on GSM", *IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)*, vol. 9, no. 3, pp. 63-67, May - Jun. 2014.

[13] Beri,N,N., "Wireless Sensor Network Based System Design for Chemical Parameter Monitoring in Water", *International Journal of Electronics, Communication & Soft Computing Science and Engineering*, vol. 3, no. 6

[14] Hsia,S,C.; Hsu,S,W.; Chang,Y,J., "Remote monitoring and smart sensing for water meter system and leakage detection", *IET Wireless Sensor Syst*., vol. 2, no. 4, pp. 402-408, Dec. 2012.

[15] Chi,Q.; Yan,H.; Zhang,C.; Pang,Z.; Xu,L,D., "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.

[16] Ciancetta,F.; D'Apice,B.; Gallo,D.; Landi,C., "Plug-n-play Smart Sensor based on Web Service", *IEEE Sensors J*., vol. 7, no. 5, pp. 882-889, May 2007.

[17] Bissi,L.; Placidi,P.; Scorzoni,A.; Elmi,I.; Zampolli,S., "Environmental Monitoring System Compliant with the IEEE1451 Standard and Featuring a Simplified Transducer Interface," *Sens. Actuators A, Phys*., vol. 137, no. 1, pp. 175-184, 2007.

[18] Rizzello,M.; Distante,C.; Siciliano,P., "A Standard Interface for Multisensor Systems", *Sensor.Environ. Control*, pp. 224-228.

[19] Vijayakumar,N., and Ramya,R., "The Real Time Monitoring of Water Quality in IoT Environment", IEEE Sponsored 2nd International Conference on Innovations in Information, Embedded and Communication systems (ICIIECS), 2015.

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