International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Design and Development of an FPGA - Based Insitu Water Quality Monitoring System

Abdulrahman B. Zaidan[1], Amlia Wong Binti Azamn[2]

Department of ECE, Fac. of Eng., International Islamic Univ. Malaysia (IIUM), Jalan Gombak, 53100 Kuala Lumpur, Malaysia
abodi.bahaa.95[at]gmail.com
amy[at]iium.edu.my

Abstract: ***There are two ways to measure and monitor water quality known as conventional method and real-time water quality method. The conventional method can be done by collecting the water samples and transfer them to the laboratory for testing the quality via different devices. However, this way of testing is cost and time consuming. In addition, it has lack of accuracy. While the other way of measuring water quality is done by integrating Internet of Things (IoT). This method could be done via using sensors and processors; therefore, it is preferable. This paper is generally concentrating on developing a multi-core reconfigurable Smart Water Quality System (SWQS) utilizing three sensors: pH, Total Dissolved Solids (TDS), and turbidity. The main objective of this article is present the work on developing a system-on-chip (SoC) design for SWQS on an FPGA. The FPGA-SoC has been used to parallelize the system's operation to increase its performance. In this work an LCD display connected to a Raspberry Pi was used to display the data captured by the FPGA in real-time. The Quartus II software was used to maintain four cores using the platform designer. The programming for the sensors were done using the embedded C language on Eclipse tool. To verify the functionality of the system, different liquids have been used for testing. pH sensor has been verified using pure water, lemon juice and milk using a pH scale of 0 to 14 to determine acidity and alkaline. pH sensor showed a value of 7 for pure water as it is neutral solution, while the pH value for milk was 8 as it is base liquid. In addition, as lemon juice is acidic, therefore pH value was approximately 2. Additionally, verifying TDS sensor was done by adding salt to the water to measure dissolved solids. TDS values raised up to approximately 1800 ppm. Finally, the turbidity sensor revealed the dust inserted in the solution. The more dust in the liquid, the more TDS value there was recorded. Based on the results, the propose FPGA-based SWQStook 300ms for each ten readings when compared to 2s for each ten readings when using anArduino processor. This work has proven that an FPGA-SoC can be used as efficient heterogenous system.***

Keywords: Smart Water Quality, Smart Water Quality Assessment, and Sensors

1. Introduction

One of the major causes of death is contaminated or polluted water. According to World Health Organization (WHO) that in 2017, 2.2 billion people are drinking water without any safety managed services and 144 million of them collect water from untreated water bodies such as lakes, streams and rivers (World Health Organization, 2017). As a result, measuring water quality all the time becomes an important issue that needs to be done. Water quality means showing the suitability of water body that is used for different usage such as drinking, cooking, cleaning and etc(World Health Organization, 2017). Each and every water usage will have different levels of chemical, biological, and physical characteristics. For instance, drinking water has specific water quality parameters such as pH level should from 6.5 to 8.5.

As there are many parameters that are required to be measured, thus there are several sensors that must be connected to a processor. As a result, systems that support these big computational loads needs a very huge power, and that will make it impossible to be commercialized.

Heterogeneous System Architecture (HSA) is a new computer platform infrastructure and associated software, which allows processors of different types and architectures to work efficiently and cooperatively in shared memory from a single source program (Kyriazis, 2012). Integrating multiple computing elements running at lower frequencies allows obtaining impressive performance capabilities at a reduced power consumption, while architectural heterogeneity enhances platform flexibility (Burgio et al., 2017).

As a result, it is needed to design a smart system that can carry out the huge computational load with low power and high performance and that is why FPGA along the ARM are going to be used to design the proposed water quality system.

1.1 Related works

There are several developed Smart Water Quality systems that have been designed to measure different water quality parameters such as pH, turbidity, total dissolved solids (TDS), electrical conductivity (EC), temperature, and more by using different kind of controllers such as Arduino, Raspberry Pi, PLC, etc. Data from the sensors are even visualized using different software or sent through transmission devices for analysis, decision making, and machine learning. Therefore, this section will present the previous studies and discuss the motivations and drawbacks.

In (Ngom et al., 2019), a smart water quality monitoring system has been designed to measure four essential water quality parameters using; pH sensor, oxidation/reduction potential (ORP) sensor, electrical conductivity (EC) sensor, and temperature
sensor. The obtained data was processed using Arduino Mega 2560 processor, transferred using LoRa transmission system to be displayed on a screen. The designer has used Arduino as it is user friendly and easy to program and implement. In addition, LoRa transmission system can

transmit the data using different bands such as medical and industrial, so there is no additional cost inutilizing LoRa. The designer has also incorporatedsolar panel to decrease the power consumption and utilize the system anywhere without worrying of having power source. However, Arduino processor is limited with the number of pins which makes it unuseful for huge systems such as water quality which has more than thirty parameters which need to be measured. Furthermore, LoRa transmission system can transmit the data for nearly 3 km only and that require the system control room to be near all the time. Furthermore, the price of the LoRa gateway is high. The above drawbacks eliminate the implementation of the system for real life application.

In addition, (Encinas, Ruiz, Cortez, & Espinoza, 2017) have implemeted a real-time water quality system that was used to monitor three water quality parameters, namely pH, temperature, and dissoloved oxygen (DO). The processing of data was done using Arduino processor. Finally, Zigbee wireless communication toolwas used for tranferring the data into either the database for storing or to the webservice for visualizing the data on an web-based application. The system was portable and cost effective comparing to other water quality systems. However, Arduino processor cannot handle many sensors interfaces as it has limit pins with I2C protocol, SPI protocol and etc. Zigbee coomuication system transfer the data for a very short distance to almost 100m.

In (Niswar et al., 2018), a water quality monitoring system wasdeveloped using sensors to measure pH, temperature, and salinity with the aid of Raspberry Pi for data prcoessing as well asMQ Telemetry Transport (MQTT) protocol and LoRa system. The overall system is complex as it utilized Arduino to connect LoRa, and Raspberry Pi for data processing. Therefore, the overall cost and power consumption is very high compared to other system. In addition, MQTT has used 3G network to transmit the data to the mobile application, which is uncovered everywhere specially rivers that are far from network towers. Not to mention that MQTT is slow transmission system and data is not encrypted which makes the system unsecure. Finally, Raspberry Pi is not enough to be used in real-time application for huge data transfer as well as it is like Arduino, it is limited with number of pins and interfaces.

Furthermore, in(Myint, Gopal, & Aung, 2017), a new water quality monitoring system was designed to measure pH, water level, turbidity, temperature, and carbon dioxide (CO_2) and utilizing FPGA board for data processing with the support of Zigbee communication system for transferring the water quality data. The designer has utilized VHDL language to design the processor and embedded C language for programming the sensors and the data was visulized using Grafana package on a desktop PC on Linux operating system. FPGA provided more flexibility and configurability comparing to other processor such as Arduino and Raspberry Pi. FPGA board has large number of pins which is not hard coded and that made it easy to choose the interface and connect many sensors to it. However, the designer used Zigbee communication tool which is costly and transfer the data for short distance. In addition, the designer had utilized only one Nios II processor, this increases the time to collect the data as it will collect the data in series instead of parallel.

With rapidly evolving standards and requirements for SWQS applications, the need for more flexible and faster development cycles, while maintaining high performance is the primary concern for system designers. FPGAs provide a promising approach to solve this problem since they can adapt their hardware based on the current needs of the SWQS applications with mid to high level of performance. Using FPGA will increase the performance compare to other processor with low performance range. In addition, FPGA provide the flexibility to the designer to select based on the budget. It could be expensive as high performance platforms and very cheap as low performance platforms.

FPGA processor is not commonly used as the processorsbecause the cost of FPGA is high and can reach up to $200, while other processors like Arduino cost around $30. In addition, the design complexity increases with FPGA. However, when it comes to speed, the FPGA has higher speed processor with frequency reaching to 1 GHz, while the Arduino is at 24MHz. Additionally, FPGA is not only used as prototype design with limited function but can also be used as end product for measuring water quality that can be used by any institution or government as it is highly functional and can be connected to many sensors and electronic circuits without any effect on the performance.

Therefore, it highly needed to use a processor such as FPGA that is more flexible with the number of pins and their interfaces unlike other processors such as Arduino and Raspberry Pi that have a smaller number of pins and have hard coded pins.

In addition, using FPGA provides a middleware layer that makes the hardware and software design easier for the developer. Furthermore, the ARM processor where the Linux application can access through the ARM terminal will allow the user to display the data of the sensors and the data might be used in machine learning, performance analysis, and decision-making software.

This research work mainly concentrates on the hardware design of SQWS using water quality sensors. The design integrates FPGA with SoC to create a customizable heterogeneous platform that segments the system functionality into smaller multiple tasks. The proposed design in this study will use two development kits, DE10 Nano SoC FPGA development kit from Intel, and Raspberry Pi development board. In the system, an internal sub-system (ARM SoC) will be used to visualize the water quality data. The Raspberry pi will be used to provide the system with all the required augments for making the implementation of prototype easier, like LCD, mouse, and keyboard. Raspberry Pi was used as Linux operating system can be install on it, therefore Linux terminal in ARM processor can be accessed from the operating system on the Raspberry Pi. The internal SoC will be part of the SWQS as the main system processor.

In addition, testing will be based on three water quality parameters that will be used for verifying and validating the functionality and reliability of the system. The utilized sensors in this work are the pH, TDS, and turbidity sensors.

2. Development of FPGA-SoC SWQS

A DE10 Nano SoC FPGA development kit was connected to the pH, TDS, and turbidity sensors. The main FPGA chip is divided into two parts. The first part focuses on processing the data from sensors while the second part is the ARM processor which has the Linux application. The ARM processor was utilised to run the Linux application. This application controls the entire system, reads the segmented and analyses data from sensors stored in the shared memory. Next step was to read the data from the ARM processor. For this, a PC or laptop can be used to display the data. In this work, a Raspberry Pi was used to replace the PC or a laptop. The Raspberry Pi processor can be connected to any screen easily same as other processor like Arduino, on the other hand Raspberry Pi was used as Linux operating system can be run on it, then the Linux application in the ARM processor could be accessed using the Linux terminal on the Raspbery Pi. The entire system is portable and could be fed power via a 20000mah power bank. Figure 1 shows proposed system blocks and data flow.

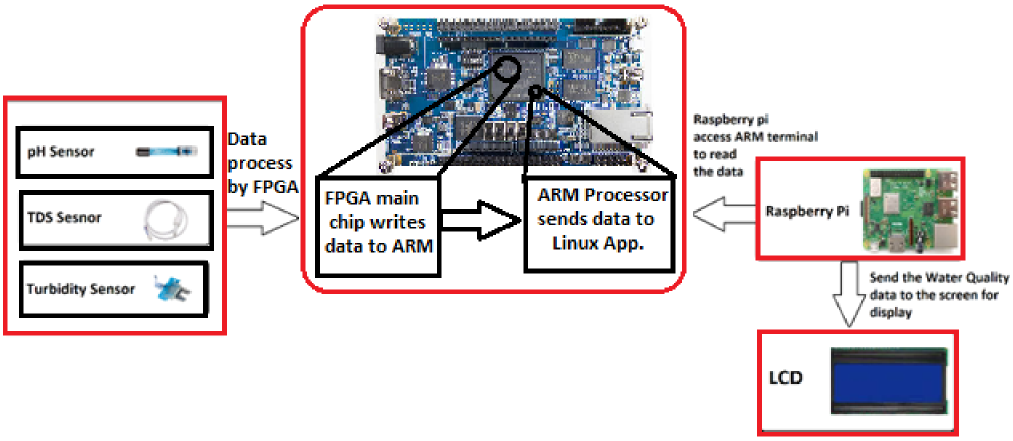

Figure 1: Proposed System Blocks and Data Flow

The prototype was tested on different types of liquids for real-time testing. The prototype design can be found in Figure 2. The following components were used for this experiment: Raspberry Pi 3 development kit, DE10 Nano FPGA-SoC development kit, pH sensor, TDS sensor, turbidity sensor, as well as a few wires and cables.

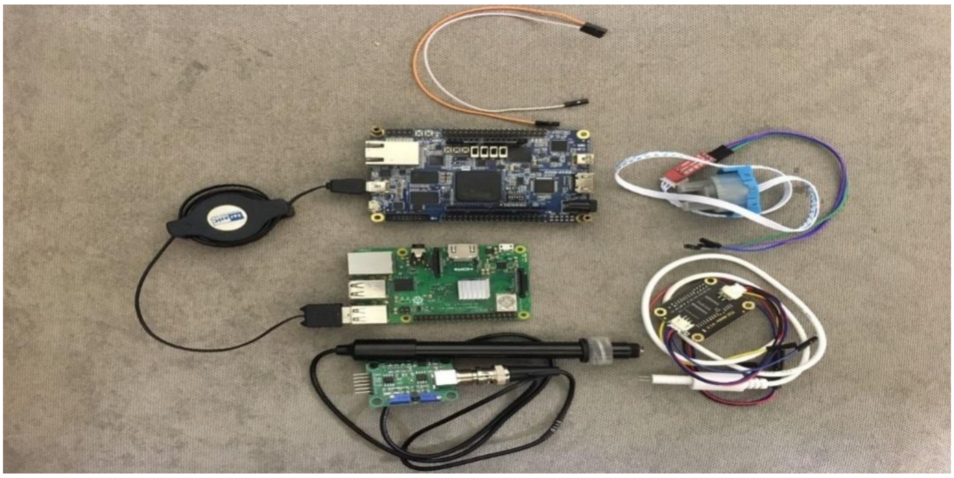

Figure 2: System Setup Components.

Figure 3 shows the proposed design block diagram. The pH sensor, TDS sensor, and turbidity sensor which are analog sensors need to be connected to an ADC. The data from the sensor are analog and it might have some niose, therefore an internal reference circuit and the sample-and-hold circuit were used to decrease the noise to get high data stability. The input signals of the pH sensor, TDS sensor, and turbidity sensor have been connected to ADC_IN0 pin, ADC_IN1, and ADC_IN3, respectively. Once the data is collected and transferred to SoC, it can be viewed using the Raspberry Pi by accessing the Linux application on ARM terminal. Therefore, USB Mini-B was utilized to connect Raspberry Pi with ARM. In addition, the Linux image has been burnt on an SD card which can be used to display the data collected from the sensors on the screen connected to Raspberry Pi. Finally, each sensor must be connected to a 5V and ground pin.

Paper ID: MR22801164044 DOI: 10.21275/MR22801164044

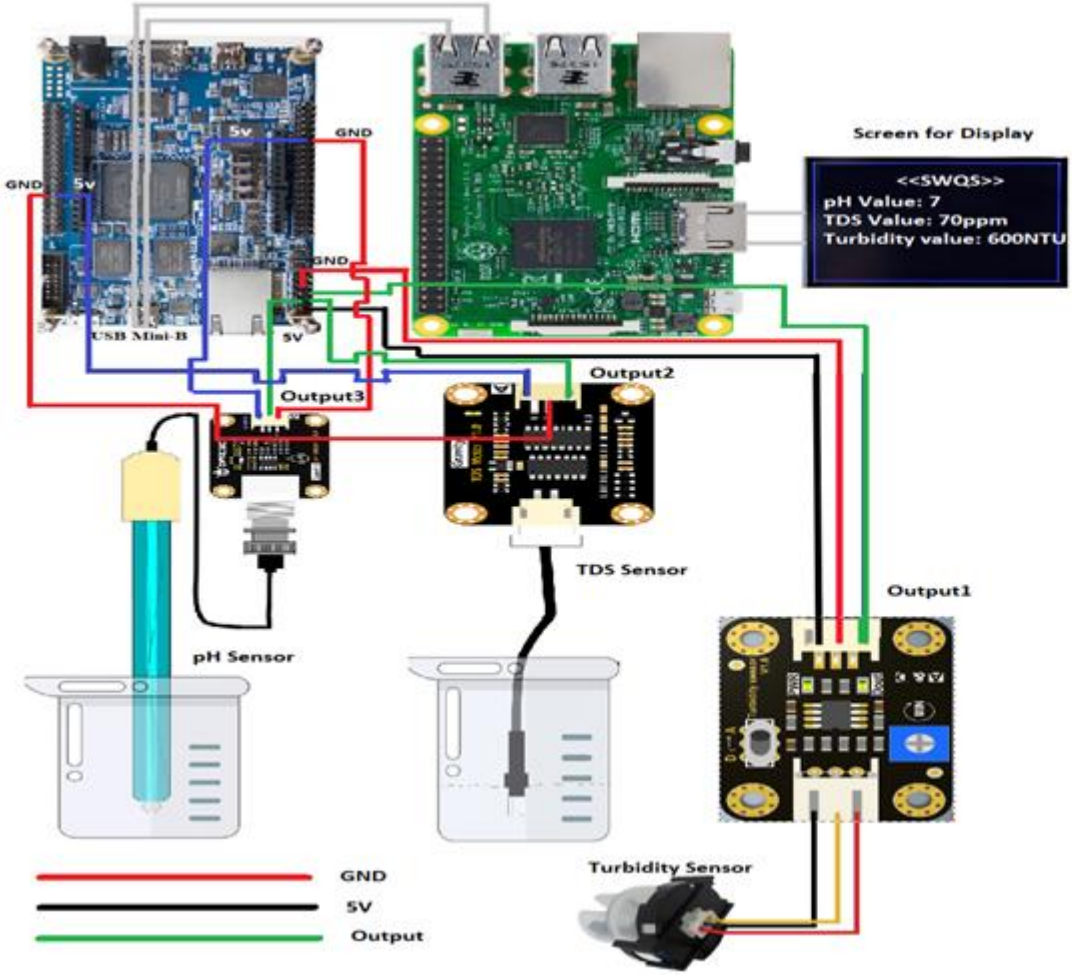

Figure 3: shows the proposed design block diagram

3. Results

pH is a measure of the relative amount of free hydrogen and hydroxyl ions in the water. Water that has more free hydrogen ions is acidic, whereas water that has more free hydroxyl ions is basic. To test the pH sensor, pure water, lemonjuice and milk were used. Pure water and salted water were used to test the TDS sensor and finally the turbidity sensor was tested on pure water and a solution of pure water mixed with some dust.

The system has been tested successfully with acceptable readings. The pH value was almost 7 for pure water, however when measuring the pH of lemon juice, the value of pH was almost 2. While when detecting pH value for milk, it shows more than 8.

TDS stands for Total Dissolved Solids and it refers to the total concentration of dissolved materials in a liquid.TDS value is measured by ppm which is parts per million. The measured value for the were between 70ppm and 74ppm. However, when salt was added to the water, the TDS values recorded was nearly 1200ppm.

Turbidity is the measurement of relative clarity of a liquid. It is an optical characteristic of water and is a measurement of the amount of light that is scattered by material in the water when a light is shined through the water sample. The higher the intensity of scattered light, the higher the turbidity. The turbidity is measured by nephelometric turbidity units (NTU). The higher the turbidity value, the more particles in it which make it unsafe especially for consumption. Pure water showed a value of nearly 600NTU, however the water with some dusts showed more than 1100NTU.

The SWQS Linux-application was tested at real-time environment. The Linux-application has been utilized to control the cores of processing elements on FPGA, decode the message that is sent from the main core that controls other cores of the sensors. and finally shows out the data collected from sensors on the Linux terminal as shown in figure 4.

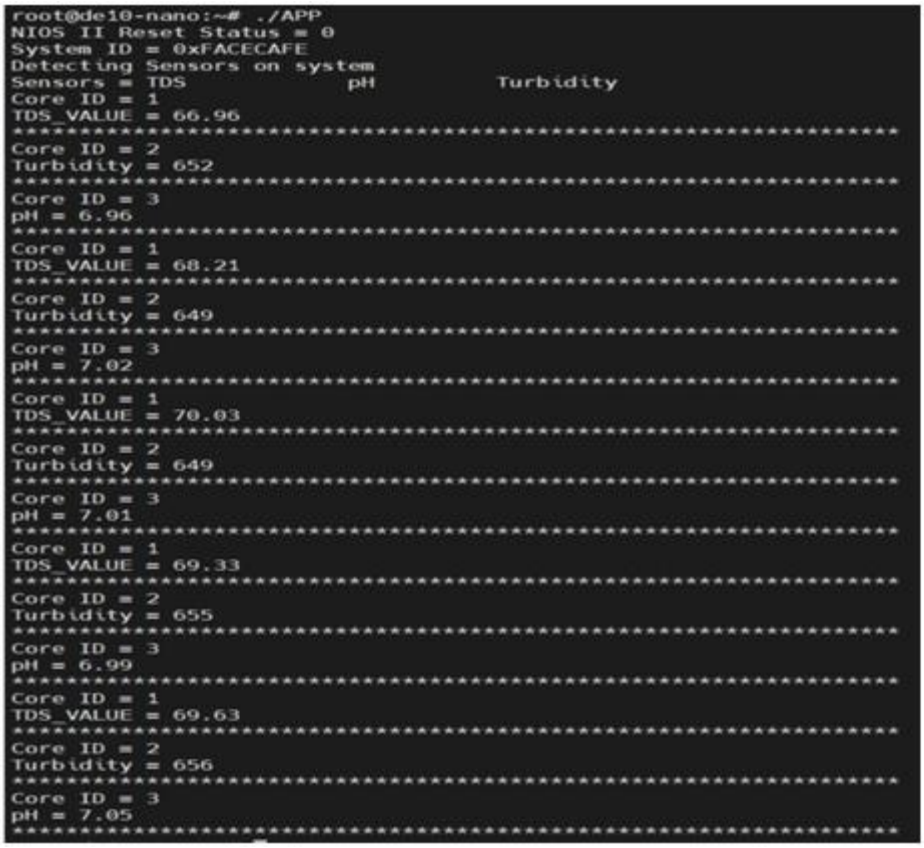

Figure 4: SWQS results on Linux-Based application.

4. Discussion

FPGA-SoC was utilized to design the proposed system, and this will provide more design flexibility. In the case of water quality monitoring system, having larger number of input-output interface is a critical since multiple sensors are normally required for the system. FPGA is a programmable board therefore, the developer may design the needed interfaces, controllers, peripherals using the Intellectual Property (IP), which is pre-made components available on FPGA. The new interfaces could be wired with the external FPGA pins.

The proposed design has been developed based on SWQS data acquisition and the system functionality. Achieving high quality SWQS needs multiple sensors and sub-system to be added to the design. Many applications can be extended to data processing, decision making, performance analysis, machine learning, and deep learning. The usage of embedded Linux operating system in the SWQ proposed system will simplify the application development. Additionally, any programming language could be used for developing the application.

5. Conclusion

This research proposed a design of SWQS hardware data acquisition based on heterogenous platform using SoC and FPGA platforms. The proposed design was tested and validated successfully. The design provided a good data acquisition design which was validated through three types of sensors, pH, TDS, and Turbidity. The hardware design was implemented on FPGA, while the software application was implemented on the SoC platform. Quartus Prime was utilised for the hardware design compilation. After that, the design was verified on FPGA based on several scenarios. Then, the prototype was implemented for real-time testing. The proposed system can be utilised as a heterogenous multicore system for several applications, one of them is the SWQ data acquisition system.

References

[1] WHO, W. H. O. (2017, July 12).*2.1 billion people lack safe drinking water at home, more than twice as many lack safe sanitation*. World Health Organization. https://www.who.int/news/item/12-07-2017-2-1-billion-people-lack-safe-drinking-water-at-home-more-than-twice-as-many-lack-safe-sanitation

[2] Burgio, P., Bertogna, M., Capodieci, N., Cavicchioli, R., Sojka, M., Houdek, P., Marongiu, A., Gai, P., Scordino, C., & Morelli, B. (2017). A software stack for next-generation automotive systems on many-core heterogeneous platforms. Microprocessors and Microsystems, 52, 299–311.

[3] Ngom, B., Diallo, M., Gueye, B., &Marilleau, N. (2019). *LoRa-based Measurement Station for Water Quality Monitoring: Case of Botanical Garden Pool.* Paper presented at the 2019 IEEE Sensors Applications Symposium (SAS).

[4] Li, L. Y., Jaafar, H., & Ramli, N. H. (2018). *Preliminary study of water quality monitoring based on WSN technology.* Paper presented at the 2018 International Conference on Computational Approach in Smart Systems Design and Applications (ICASSDA).

[5] Khatri, P., Gupta, K. K., & Gupta, R. K. (2020). Assessment of Water Quality Parameters in Real-Time Environment. *SN Computer Science, 1*(6), 1-9.
[6] Myint, C. Z., Gopal, L., & Aung, Y. L. (2017). *Reconfigurable smart water quality monitoring system in IoT environment.* Paper presented at the 2017 IEEE/ACIS 16th international conference on computer and information science (ICIS).

Author Profile

Dr. Amelia Wong Azman, graduated with a First Class Honours in Electronics from University of Southampton, United Kingdom in 2004. she continued her studies in Australia and was conferred the Ph.D 2011. During her time in Australia, she was also a graduate research assistant (GRA) at National ICT Australia (NICTA) - a body which its main research area is on smart surveillances. Her Ph.D work investigates further the concept of hardware and software co-design in an embedded system design in order to optimize the available hardware and software resources.

A well experienced in the field of software and hardware. **Abdulrahman** has graduated with honours from the faculty of enginerring, electronic and computer information engineering, International Islamic University Malaysia. He continued his masters in the same university.