International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 4 Issue 2, February 2020 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Implementation of Low-Cost Radon Measuring System for Air Quality Monitoring

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ABSTRACT

Because inhaling radon and its radioactive-decay products causes irradiation of lung tissue, the radon data obtained from houses and workplaces need to be transferred using Wi-Fi and the Internet to a database on a radon-monitoring server system. To do this, a PIN photodiode radon measuring system was implemented and the ESP8266 Wi-Fi module was used for wireless communication. Through some experimental studies, we showed that the data transmission using these Wi-Fi modules was very successful.

KEYWORDS: *radon, Wi-Fi, PIN photodiode, radon monitoring, wireless communication*

How to cite this paper: Jun-Yong Kim | Gyu-Sik Kim "Implementation of Low-Cost Radon Measuring System for Air Quality Monitoring" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-4 | Issue-2, February 2020, pp.579-582, URL: www.ijtsrd.com/papers/ijtsrd30075.pdf

IJTSRD30075

I. INRODUCTION

Radon is an invisible, odorless, and chemically inactive radioactive gas produced by the decay of uranium ore. Because it is inert and does not chemically bond to elements, it is released from soil into the atmosphere. Radon is emitted almost everywhere on earth, but some geographical regions have a higher concentration than others do. When radon decays, it releases alpha particles with energy of 5.5 Mega-electrovolts (MeV). Because inhaling radon and its radioactive-decay products causes irradiation of lung tissue, prolonged exposure to a high concentration of radon significantly increases the risk of developing cancer. It has been reported that the U.S. Environmental Protection Agency estimates that exposure to naturally occurring radon leads to 21,000 lung cancer deaths nationwide each year, making radon the nation's primary environmental health threat, second only to cigarette smoking, as a cause of fatal lung cancer. Various types of equipment and components have been proposed for use in effective radon detection [1, 2, 3, 4, 5]. In this paper, a radon counter using a PIN photodiode radon-sensor module was discussed. Using a linear regression analysis technique, the measured radon counts per hour of the implemented PIN photodiode radon counters could be calibrated to Bq/m^3 which is a unit of radon concentration by comparing with the measured radon concentration data of RAD7. This radon counter can be used to measure radon concentration of the indoor air in houses and workplaces. A radon monitoring and alarm system was also discussed [6]. The data collected by the radon counters in houses and workplaces was transferred using Wi-Fi and the Internet to a radon-monitoring database created on a server, which stored client data, specifically, names, addresses, phone numbers, email addresses, and radon-counter serial numbers. If the measured radon concentration was over 148 Bq/m^3 for seven consecutive days, it sent a warning message to the client. If this radon remote-sensing Wi-Fi-based monitoring system is used in army barracks, classrooms, and country houses where there is a risk of high levels of radon exposure, soldiers, students, and residents could be protected from the dangers of radon exposure.

II. Air Quality Monitoring Using Radon Data

2.1. Radon measuring systems:

A commercial PIN photodiode can be used to detect radiation, and particularly, alpha particles. It is low cost, has good quantum efficiency, and good energy resolution. It can also work with a low bias voltage. A PIN photodiode is more widely used than a conventional photomultiplier tube (PMT) because it requires less biasing to operate and it is very compact. The PIN photodiode sensor module shown in Fig. 1 was used to detect radon gas in our tests.

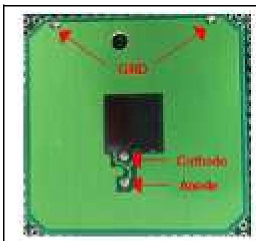
	Module size	43 x43 mm
	Sensor size	10 x 10 mm

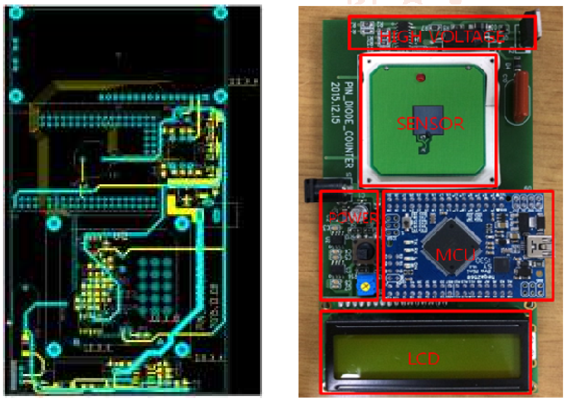
Fig.1. PIN photodiode sensor module

The Mega 2560 is a microcontroller board based on the Atmega 2560. It has 54 digital input/output pins (of which 15 can be used as Pulse Width Modulation (PWM) outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB port, a power jack, an in-circuit serial programming (ICSP) header, and a reset button. It contains everything needed to support the microcontroller; it just needs to be connected to a computer with a USB cable or powered with an AC-to-DC adapter or battery. The Mega 2560 board is compatible with most shields designed for the Uno and the older Duemilanove and Diecimila boards. The board is shown in Fig. 2

Fig.2. Arduino Mega 2560 board

2.2. Assembling of modules:

In our experiments, we used a radon counter assembled from very low-cost consumer electronics. The circuit designs for the power, high voltage generator, LCD, switch, LED, buzzer, microprocessor control unit (MCU), and sensor circuit was done. Using these circuit diagrams, we developed the PIN photodiode radon-counter printed circuit board (PCB) layout shown in Fig. 3 (a). We then assembled the PIN photodiode radon counter shown in Fig. 3 (b).



(a) (b)

Fig.3. PCB layout (a) and assembled PIN photodiode radon counter (b)

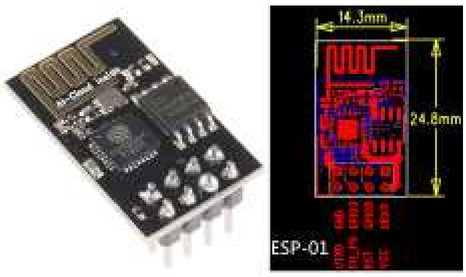
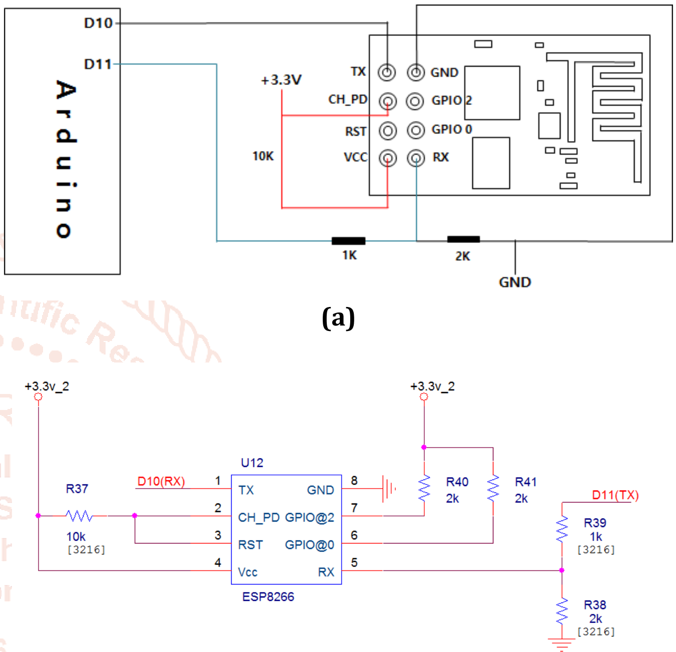


Fig.4. ESP8266 Wi-Fi module

2.3. Wi-Fi modules:

The ESP8266 Wi-Fi module is a self-contained system-on-chip (SOC) with integrated TCP/IP protocol stacks that can give any microcontroller access to a Wi-Fi network. The ESP8266 is capable of either hosting an application or offloading all Wi-Fi networking functions to another application processor. Each ESP8266 module comes pre-programmed with AT Command Set firmware, meaning the module can be hooked up to an Arduino device with about the same Wi-Fi ability as a Wi-Fi shield. The ESP8266 module is an extremely cost-effective board with a huge, and ever growing, community of users. This module has powerful enough on-board processing and storage capability to allow it to be integrated with the sensors and other application-specific devices through its general-purpose input/outputs (GPIOs), with minimal development up-front and minimal loading during runtime. Its high degree of on-chip integration allows for minimal external circuitry. The front-end module is designed to occupy minimal PCB space. The ESP8266 Wi-Fi module is shown in Fig. 4.



(a)

(b)

Fig.5. Interface of the ESP8266 Wi-Fi module to Arduino MCU

The logic connections between the Arduino and the ESP8266 are very simple: the ESP Rx connects to the Arduino Tx, and the ESP Tx connects to the Arduino Rx; however, the ESP8266 runs off 3.3V, while Arduino pins run off 5V. Before connecting them, it is necessary to provide a way to reconcile these voltages, or the ESP might be damaged. In order to adjust the voltage between the Tx/Rx pins, a simple resistor circuit was used as shown in Fig. 5. Either Access Point (AP) mode or Station mode (for the ESP8266) was chosen by the command of Arduino MCU. Station mode is the default-operating mode for the ESP8266 adapter. In this mode, the ESP8266 adapter operates as a client that connects to a Wi-Fi access point. This mode is used to connect a Wi-Fi adapter to a wireless network. In AP mode, the adapter acts as an access point enabling other Wi-Fi adapters to connect to it; therefore, the adapter can be used to create one's own wireless network. In Station mode, the ESP8266 Wi-Fi module receives the measured radon-concentration data from the radon counter's MCU using serial communication. It then sends the data to the radon monitoring server system over the Internet. The ESP8266 Wi-Fi module connected to the implemented radon counter is shown in Fig. 6. The implemented radon measuring system with ESP8266 Wi-Fi module is shown in Fig. 7.

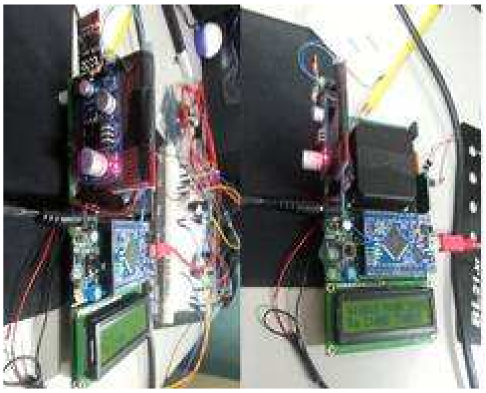


Fig.6. ESP8266 Wi-Fi module connected to the implemented radon counter

Fig.7. Radon measuring system with ESP8266 Wi-Fi module

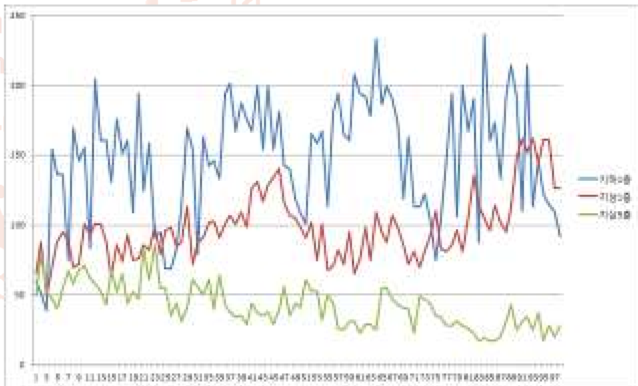
2.4. Radon monitoring and warning system:

For our experiments, we used a radon measuring system with a PIN photodiode radon-sensor module. These were used to measure the radon concentration of indoor air in houses and workplaces. A radon monitoring and alarm system was also used. The radon concentration data obtained from houses and workplaces was transferred using Wi-Fi and the Internet to a database on a radon-monitoring server system (Fig. 8). Fig. 9 shows the screen shot of radon monitoring system

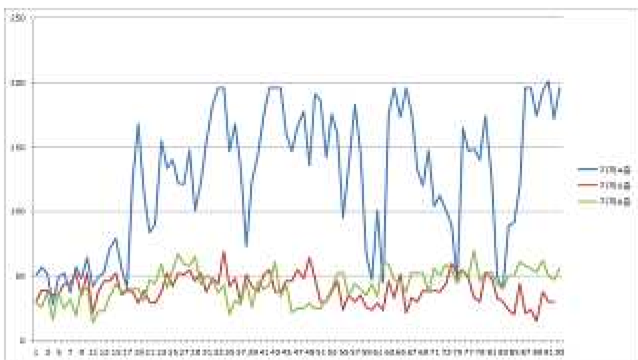
Fig.8. Concept of Wi-Fi based radon monitoring

Fig.9. Screen shot of radon monitoring system

Figure 10 shows the results of monitoring the radon concentration data of the building A. The radon concentration is measured for about 100 hours. The radon concentration on the first basement floor was above the standard of 148 Bq/m^3 . Figure 11 shows the results of monitoring the radon concentration data of the building B. On the ground, there is a shopping mall that has been closed down, and the building is being used as a substation from the fourth to sixth basement levels. As an unmanned substation where no one resides, there is a closed monitoring room on the fourth basement floor, a transformer room on the fifth basement floor, and a cable processing room on the sixth basement floor, which is an air passageway called the equipment return entrance, to measure radon concentration in a relatively open area. The problem is judged to have occurred because the fourth basement floor has exceeded the reference level and is enclosed.



(x-axis : hour, y-axis : Bq/m^3)
(blue line : first basement floor, red line : ground floor, green line : fifth floor)
Fig.10. Radon data of the building A



(x-axis : hour, y-axis : Bq/m^3)
(blue line : fourth basement floor, red line : fifth basement floor, green line : sixth basement floor)
Fig.11. Radon data of the building B

III. Concluding Remarks

Because inhaling radon and its radioactive-decay products causes irradiation of lung tissue, prolonged exposure to a high concentration of radon significantly increases the risk of developing cancer. So, the radon concentration data obtained from houses and workplaces need to be transferred using Wi-Fi and the Internet to a database on a radon-monitoring server system. To do this, a radon counter using a PIN photodiode radon-sensor module was implemented and the ESP8266 Wi-Fi module was used. Through some experimental studies, we showed that the data transmission using these Wi-Fi modules was very successful.

Acknowledgment

This work was also supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. 2019R1H1A 2101157).

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