Experimental Study of a Wi-Fi Module for Radon Data Communication

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ABSTRACT

Radon is an invisible, odorless, and chemically inactive radioactive gas produced by the decay of uranium ore. Various types of equipment and components have been proposed for use in effective radon detection. In this paper, we describe a radon detector that uses a PIN photodiode radon-sensor module and a Wi-Fi-based radon monitoring system. Based on our studies, we believe that this system would be helpful in protecting many people from the dangers associated with radon exposure.

Keywords: radon, radon detection, radon sensor module, Wi-Fi, monitoring system

I. Introduction

Radon is a natural, inert, invisible, odorless, chemically inactive, and radioactive gas emitted by the earth. It is produced by the decay of uranium ore, such as radium, actinium, or thorium. 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. 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.

There are many commercial instruments and techniques available for measuring radon indoors. In [1], highly sensitive, electrostatic collection chambers using Columbia Resin 39 (CR-39) plastic track detectors were developed for measuring low-level radon. In [2], the unique characteristics and the shortcomings of track detectors for neutron and radon dosimetry is described and compared with those of alternative detector systems. In [3], low-cost alpha-particle sensor systems using special Positive Metal-Oxide Semiconductor (PMOS) transistors in a floating n-well were developed for radon and radon-daughter monitoring and dosimetry. In [4], a radon detector employed an electrically charged, pressed, porous metal filter that permitted radon-gas diffusion while blocking ambient light. It readily trapped both attached and unattached Polonium-214 (Po-214) and Polonium 218 (Po-2l8) ions present in gas passing through the filter. The filter was positively charged relative to the unbiased PN junction of a photo-diode detector within a detection chamber. In [5], an alpha particle detector was designed using a commercial silicon photodiode. An application of a silicon photodiode detector for radon progeny measurements is presented in [6]. In [7], a high-sensitivity radon detector that uses an electrostatic collection and a PIN photodiode for air and water was developed. A calibration system for the humidity-dependence measurement has also been developed. In [8], The PIN photodiode radon detector was improved for the highly sensitive measurement of low-level radon concentrations. The system was shown to have sensitivity to radon concentrations as low as 1.6 mBq/m^3. In [9], a super high-sensitivity radon detector for water was developed. This detector is used as a real-time monitor of radon concentration in water at the Super-Kamiokande neutrino observatory in Japan. In [10], they showed that silicon PIN photodiodes could be successfully used for thermal neutron measurements with ^{6}LiF converters and tritons created in the converter

were very well detected by the diode. In [11], they developed a low-cost continuous radon measurement system using a silicon PIN photodiode. It could be applied to laboratory and field determinations, and to measure accurately radon emanation rates from porous materials. In [12], a radon in air detecting device using a silicon PIN photodiode was developed and studied. They found that an inverse bias voltage of -9 V was good choice for measuring. In [13], they assessed the performance of the Complementary Metal-Oxide Semiconductor (CMOS) electronic system for α-particle detection from sources and in a ^{222}Rn atmosphere and compared the experimental results with those obtained from conventional methods. In [14], an integrated system-on-chip (SoC) has been designed in 0.6 μm CMOS mixed analog/digital technology, and tested for high rate alpha particle counting. In [15], they presented the complete electronic board of the future electronic radon monitor (ERM): it was made of three independent AlphaRad chips running in parallel, mounted on a small printed-circuit board which included a numeric block for data treatment based on a Xilinx programmable gate array. In [16], they described a fully standalone compact electronic monitor for atmospheric ^{222}Rn, based on a new CMOS SoC. In [17], a passive direct-reading radon monitor utilizing a custom α particle detecting MOS integrated circuit and electrostatic radon progeny concentrator has been designed. In [18], a silicon PIN photodiode was designed and fabricated in consideration of low-leakage-current and high-bias-voltage application. In [19], a fast-responding passive radon detector using electrostatic concentration and enhanced readout electronics has been designed. In [20], the system is developed which monitors the radon level, using a PIN diode for detecting the radon particles and a data processing module with Wi-Fi communication capabilities for the transmission and management of measurement results. In [21], an electrostatic concentrator constructed by metalizing a plastic funnel is used to focus charged radon progeny onto the exposed surface of an optical image sensor from a webcam. Alpha particles emitted by the collected progeny strike the image sensor, generating sufficient charge to completely saturate one or more pixels. In [22], a radon counter using PIN photodiode radon sensor module was implemented. Through experimental studies, they found that the PIN photodiode sensor module could be used for a radon counter implementation.

For our experiments, we used a radon counter with a PIN photodiode radon-sensor module. These radon counters were used to measure the radon concentration of indoor air in houses and workplaces. 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.

II. PIN Photodiode Radon Counter

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.
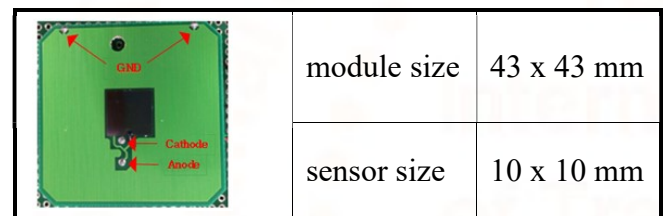

| | module size | 43 x 43 mm |
| | sensor size | 10 x 10 mm |

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 board is shown in Fig. 2.

Fig 2: Arduino Mega 2560 board

A liquid crystal display (LCD) screen is an electronic display module found in a wide range of applications. The 16x2 LCD display, the most basic, most commonly used module is found in many different devices and circuits. These modules are preferred over the 7-

segment and other multi-segment light-emitting diodes (LEDs) because LCDs are economical; easily programmable; and they have no limitations when it comes to displaying special characters, custom characters, and animations. A 16x2 LCD is a 16-character by two-line display. We used an LCD with a 5x7-pixel matrix in our experiments. The LCD has two registers: Command and Data. The Command register stores the instructions sent to the LCD. A command is an instruction sent to the LCD telling it to perform a predefined task, such as initializing the screen, clearing the screen, setting the cursor position, controlling the display, etc. The Data register stores the data to be displayed on the LCD. The LCD display shown in Fig. 3 is an LCD module (BC4915AYPLEH) that shows the level of radon gas in pCi/L. The display range is from 0.0 to 999.9. The radon counter we developed was designed to notify a user of the level of radon gas. It is updated every hour that there is a change in the level of radon gas.
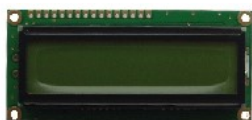

Fig 3: LCD module (BC4915AYPLEH)

Using the circuit designs for the power, high voltage generator, LCD, switch, LED, buzzer, microprocessor control unit (MCU), and sensor circuit, we developed the PIN photodiode radon-counter printed circuit board (PCB) layout shown in Fig. 4 (a). We then assembled the PIN photodiode radon counter shown in Fig. 4 (b).
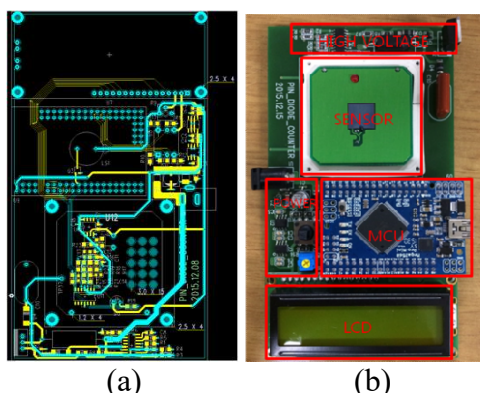

(a)   (b)
Fig 4: PCB layout (a) and assembled PIN photodiode radon counter (b)

III. Wi-Fi Module

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. 5.

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. 6. 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. 7.
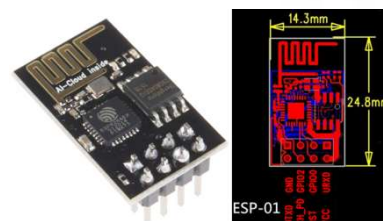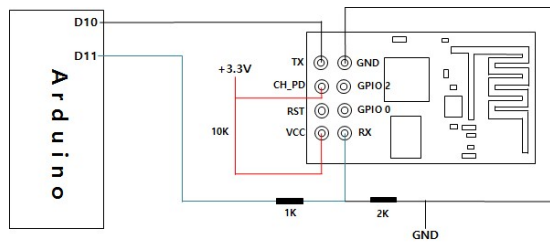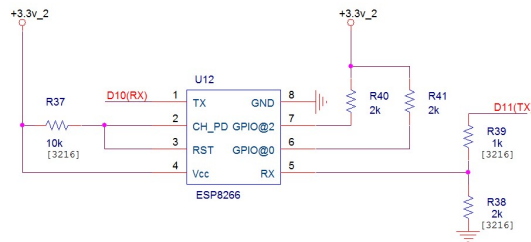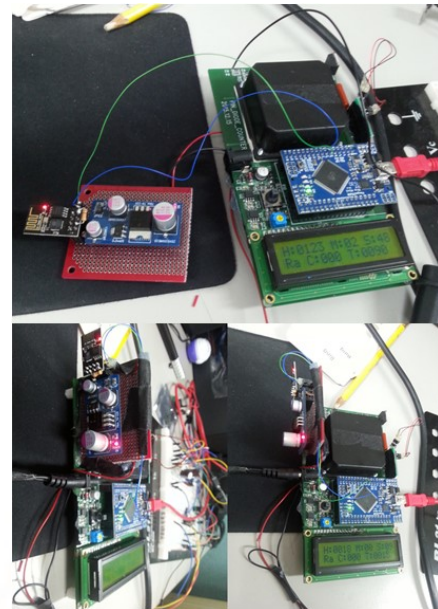

Fig 5: ESP8266 Wi-Fi module

(a)

(b)

Fig 6: Interface of the ESP8266 Wi-Fi module to Arduino MCU

Fig 7: ESP8266 Wi-Fi module connected to the implemented radon counter

In Fig. 8, we show how a new service set identifier (SSID) and password were assigned to a Wi-Fi router so that the radon counter could be connected to a Wi-Fi router using a smartphone. First, the ESP8266 was converted to AP mode. The ESP8266 SSID and password were then set to new values using the smartphone's Wi-Fi. After using the smartphone's web browser to access the ESP8266 web server (address 192.168.4.1), the Wi-Fi router's SSID and password were reset from the smartphone screen. Once all of these initialization processes were complete, the ESP8266 should be converted to Station mode from AP mode. Then, the radon counter could connect to the Wi-Fi router using the router's SSID and the password stored in the ESP8266's flash memory. After that, the measured radon-concentration data was transferred to the server.
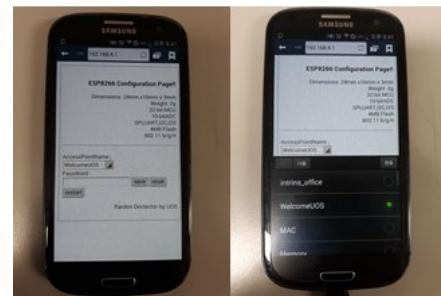

Fig 8: Assigning of new SSID and password to a Wi-Fi router

IV. Experimental Results and Discussion

In order to investigate the performance of the implemented the PIN photodiode radon counter, the methyl methacrylate box was made as shown in Fig. 9. Fig. 10 shows the accumulated radon counts measured in an implemented PIN photodiode radon counter. The total counts of 730 alpha particles were detected for 170 hours.
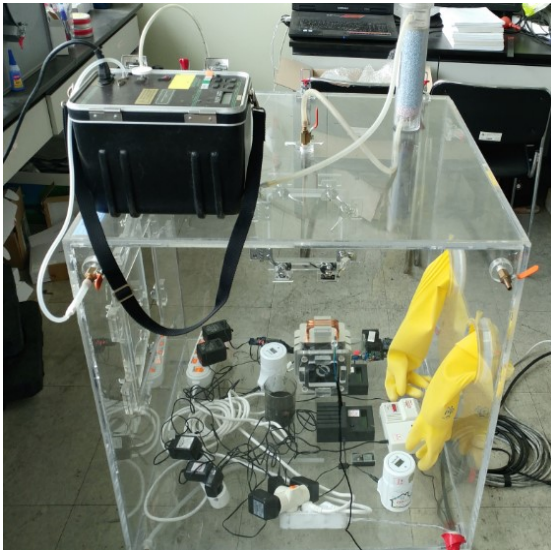
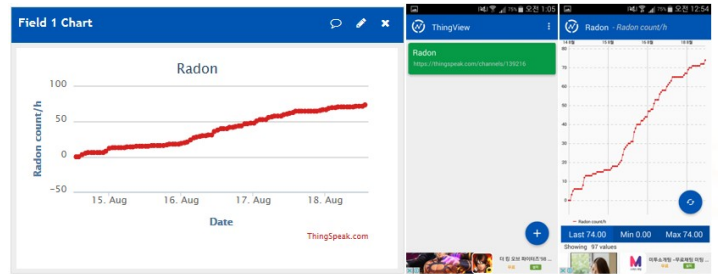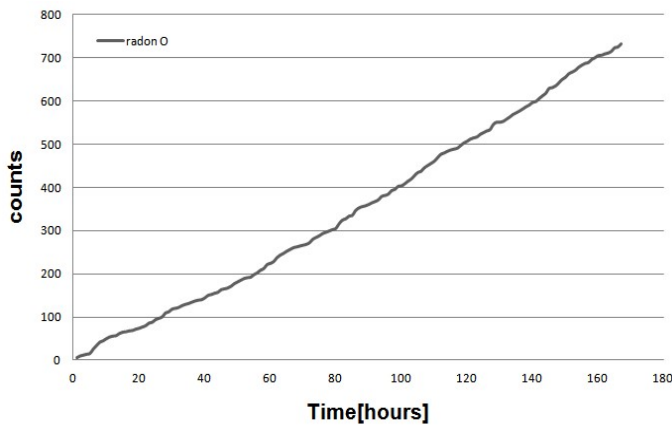**Fig 9: Experimental set-up for performance test**

Fig 10: Accumulated radon counts measured in an implemented PIN photodiode radon counter

Next, the ESP8266 Wi-Fi module connected to the implemented radon counter was tested. The counted radon data for an hour was transferred to the server PC using a Wi-Fi module. This was done for 25 hours as shown in Fig. 11.

Fig. 12 shows the server transmission confirmation of radon accumulated data. Fig. 13 shows the comparison of ROM data of radon counter and Wi-Fi transferred data. As can be seen in Fig. 13, the radon data was transferred without fail to the server PC using Wi-Fi module.
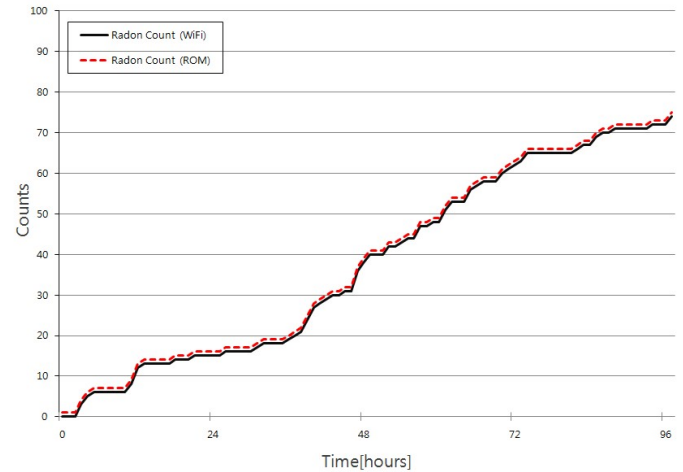

Fig 11: Server transmission confirmation of radon measured data : PC screen (left) and Smartphone (right)

Fig 12: Server transmission confirmation of radon accumulated data : PC screen (left) and Smartphone (right)

Fig 13: Comparison of ROM data of radon counter and Wi-Fi transferred data.

V. Concluding Remarks

In this paper, a radon counter using a PIN photodiode radon-sensor module was discussed. This radon counter can be used to measure radon concentration of the indoor air in houses and workplaces. 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 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.

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