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Implementation of a Radon Counter Measuring Apparatus using CCD Image Sensor Module

Chungyong Kim, Gyu-Sik Kim
Department of Electrical and Computer Engineering, University of Seoul
Seoul, Korea

ABSTRACT
Radon is an invisible, odorless 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 measuring apparatus that uses an analog CCD image sensor module. 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, CCD image sensor module, radon exposure*

I. INTRODUCTION
Radon is a natural, inert, invisible, odorless, chemically inactive, and radioactive gas emitted by the earth. Because it is inert and does not chemically bond to elements, it is released from soil into the atmosphere. 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], 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 [2], The PIN photodiode radon detector was improved for the highly sensitive measurement of low-level radon concentrations. The system was shown to have a sensitivity to radon concentrations as low as 1.6 mBq/ m^3. In [3], 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 [4], 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 [5], 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 [6], 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 [7], 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 [8], 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.

For our experiments, we implemented a radon measuring apparatus using a CCD image sensors module. The radon measuring apparatus could be used to measure the radon concentration of indoor air in houses and workplaces.

II. Radon Measuring Apparatus Using CCD Image Sensor Module

2.1 CCD image sensors: An image sensor is a sensor that detects and conveys the information that constitutes an image. It does so by converting the variable attenuation of light waves (as they pass through or reflect off objects) into signals, small bursts of current that convey the information. The waves can be light or other electromagnetic radiation. Image sensors are used in electronic imaging devices of both analog and digital types, which include digital cameras, camera modules, medical imaging equipment, night vision equipment such as thermal imaging devices, radar, sonar, and others. When an image is captured by a network camera, the light passes through the lens and falls on the image sensor. The image sensor consists of picture elements, also called pixels, which register the amount of light that falls on them. They convert the received amount of light into a corresponding number of electrons. The stronger the light, the more electrons are generated. The electrons are converted into voltage and then transformed into numbers by means of an A/D-converter. The signal constituted by the numbers is processed by electronic circuits inside the camera.

CCD image sensors accomplish task of capturing light and converting it into electrical signals. Each cell of a CCD image sensor is an analog device. When light strikes the chip, it is held as a small electrical charge in each photo sensor. The charges are converted to voltage signal for one pixel at a time as they are read from the chip. This signal is amplified outside the sensor (Figure 1). CCD sensors have had some advantages compared to CMOS sensors, such as better light sensitivity and less noise. In recent years, however, these differences have disappeared. The disadvantages of CCD sensors are that they are analog components that require more electronic circuitry outside the sensor. CCD sensors also require a higher data rate, since everything has to go through just one output amplifier, or a few output amplifiers.

2.2 Arduino MCU and LCD display modules: The Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. The Mega 2560 board is compatible with most shields designed for the Uno and the former boards Duemilanove or Diecimila.

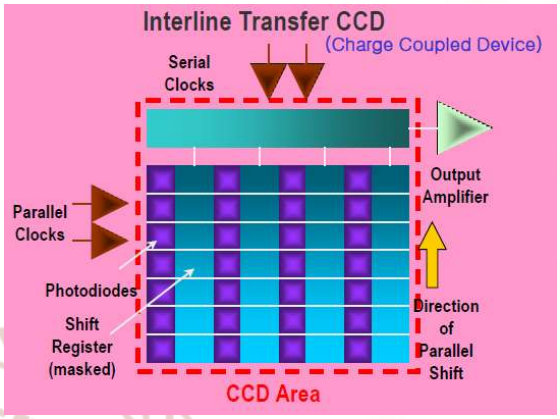


Fig. 1. CCD operation principle

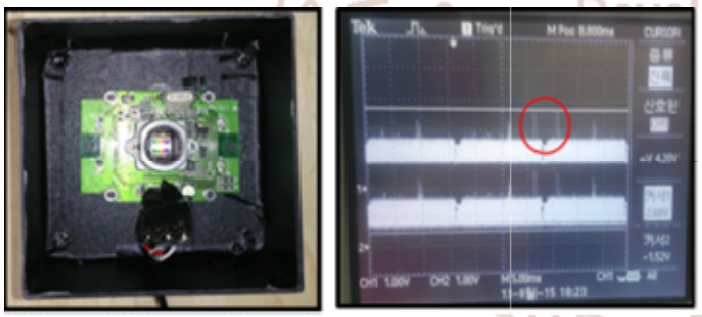
LCD (Liquid Crystal Display) screen is an electronic display module and find a wide range of applications. A 16x2 LCD display is very basic module and is very commonly used in various devices and circuits. These modules are preferred over seven segments and other multi segment LEDs. The reasons being: LCDs are economical; easily programmable; have no limitation of displaying special & even custom characters (unlike in seven segments), animations and so on. A 16x2 LCD means it can display 16 characters per line and there are 2 such lines. In this LCD each character is displayed in 5x7 pixel matrix. This LCD has two registers, namely, Command and Data. The command register stores the command instructions given to the LCD. A command is an instruction given to LCD to do a predefined task like initializing it, clearing its screen, setting the cursor position, controlling display etc. The data register stores the data to be displayed on the LCD. The data is the ASCII value of the character to be displayed on the LCD.

The LCD display chosen in this paper is a LCD module (BC4915AYPLEH) that shows the level of radon gas in Pico Curies per liter (pCi/L). The display range is 0.0 to 999.9. The radon counter developed in this paper is designed to notify the user of the level of radon gas on either a short-term or long-term basis, and is updated every hour if there is a change in the level of radon gas.

2.3 Radon detection using an analog CCD sensor module: Figure 2 shows the analog CCD image sensor module used for our experimental studies.

Fig.2. CCD image sensor module used for experimental studies

CCD image sensors are used to detect the alpha emissions from radon progeny, in particular, 218Po and 214Po which have been concentrated onto the image sensor surface. The cover glass of a CCD camera module should be removed in order to make the alpha emissions hit the image sensor surface. As can be seen in Fig. 3 (a), the CCD image sensor module was placed in a light-blocking chamber. Normally, the output voltage of the CCD image sensor signal was kept between 1.78V and 2V. But, when the radon particle was detected, it was 2.68V as shown in Fig. 3 (b) (two pulses in a circle). Therefore, the comparator circuit with reference voltage of 2.4V can be used for the radon detection.



(a) (b)

Fig. 3. CCD sensor module in a light-blocking chamber and detected radon

In order to investigate the performance of the implemented CCD sensor-based radon measuring apparatus, the commercial radon detector : Safety Siren Pro Series3 - HS71512 was used. The methyl methacrylate box was made for these experiments. Radon emitting soil was placed on the shelf. Then, these were set under the shelf as shown in Fig. 4.

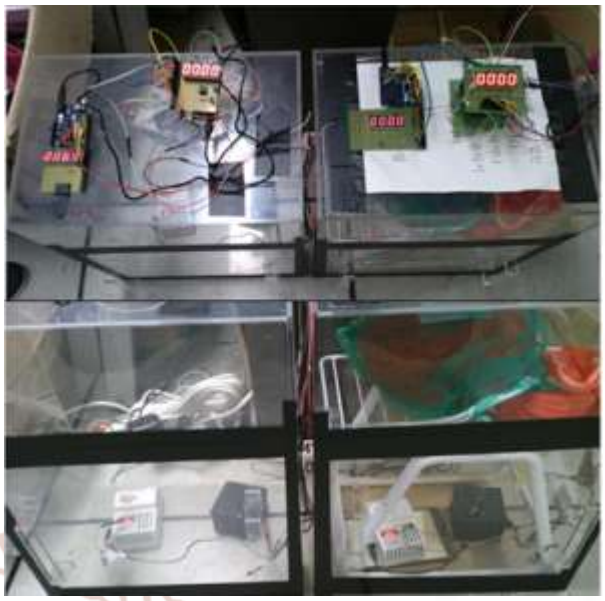


Fig. 4. Experimental set-up for performance test

III. Experimental Results and Discussion

The RAD7 radon detector, manufactured by Durridge Company in the United States, is a highly versatile instrument that forms the basis of a comprehensive radon measurement system. It is used in many different modes for different purposes.

The analog CCD radon measuring apparatus implemented in our tests was calibrated using the RAD7 electronic radon detector. The RAD7 uses an air pump and a solid-state alpha detector that is made of semiconductor material that converts alpha radiation directly into an electrical signal. It has desiccant ($CaSO_4$) tubes and inlet filters (pore size 1 μm) that block fine dust particles and radon daughters from entering the radon test chamber. The RAD7's internal sample cell is a 0.7-liter hemisphere coated on the inside with an electrical conductor. A silicon alpha detector occupies the center of the hemisphere.

The methyl methacrylate box made for radon concentration calibration is shown in Fig. 5. The calibration experiments were conducted for 154 h using a varied concentration of radon gas. Using a linear regression-analysis technique, the radon counts per hour of the implemented analog CCD radon counters were calibrated to pCi/L which is a unit of radon concentration. Fig. 6 shows the linear regression analysis for 12 hours data average. This experiment result suggests that the implemented analog CCD radon measuring apparatus could prove useful for measuring and monitoring radon concentration of the indoor air in a house or a

workplace.

IV. 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.

In this paper, a radon measuring apparatus using a CCD radon-sensor module was discussed. This 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. 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.

Fig. 5. Methyl methacrylate box made for radon concentration calibration

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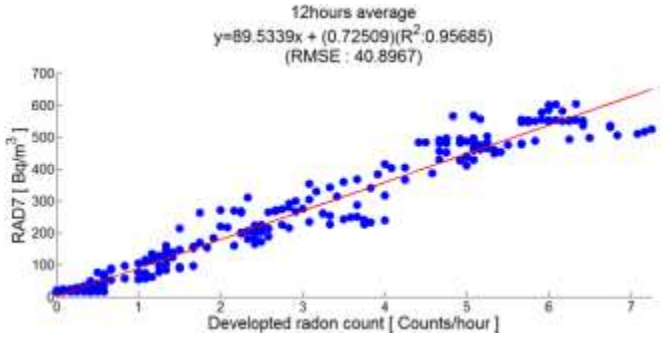

Fig. 6. Linear regression analysis for 12 hour averaged radon data

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