mekatronika – Journal of Intelligent Manufacturing & Mechatronics
VOL. 01, ISSUE 01, 14 – 20
DOI: https://doi.org/10.15282/mekatronika.v1i1.978

ORIGINAL ARTICLE

Wireless Wide Area Radiation Monitoring Network Using Internet of Things

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ABSTRACT – The nuclear disaster in Fukushima motivated the need for the development of a wireless wide area radiation monitoring network that is capable of measuring and remotely displaying radiation level in the affected zones without the concomitant increase in exposure of radiation to the workers. This paper describes the development of such a system using a commercially available Geiger-Mueller (GM) counter that can be deployed in a radiation-infested area. The GM counter transmits radiation readings at a fixed interval wirelessly to a web interface which is then shared in real time to remote stations. The proposed system employs the Internet of Things (IoT) platform, ThingSpeak, as an interface for sharing the information via the Internet. The system is modular as such that the number of stations can be readily added. The experimental results demonstrate that the proposed monitoring system is feasible for radiation monitoring.

ARTICLE HISTORY
Received: 9 December 2018
Accepted: 3 January 2019

KEYWORDS
radiation monitoring
real-time monitoring
wireless network

Introduction

The establishment of wireless wide area radiation monitoring network has gained due attention primarily owing to Fukushima Daiichi nuclear calamity triggered by the magnitude 9.0 earthquake and the ensuing tsunami in 2011 [1]. The use of such a system may assist security forces and authorities to determine the levels of radiation of the infected zones without compromising the life of the workers [2]. It is worth noting that wireless monitoring network and to a certain extent the employment of the Internet of Things (IoT) has been used for environmental monitoring in the field of agricultural, habitat, indoor living, greenhouse, climate, forest, animal tracking and logistic purposes amongst others [3]–[11].

The release of radiation becomes significant in the event that the failure of the containment unit transpires. The problem caused by such major incident can lead to the dispersion of high levels of radioactivity within the vicinity of the plant which would consequently pose a threat to human as well as biological life [12]. Hence, it is desirable to have a continuous radiation monitoring system network preinstalled in the downwind direction beyond the Exclusion Zone of the nuclear power plant (NPP) which is able to provide real-time of measurement of the radiation. In addition, the International Atomic Energy Agency (IAEA) through its nuclear safety report suggests that more could be done in order to further strengthen such management through the use of technology [13].

The backbone of any wireless radiation monitoring system consists of three major sub-systems namely the detection sensor, wireless communication as well as the monitoring interface. Although different sensors have been investigated, i.e. glass scintillators [14] and silicon dosimeter [15][x], nonetheless, such sensors are deemed unsuitable as it ability to detect is limited to only gamma rays and neutron [16]. It is also worth noting that different type of wireless sensor networks (WSN) have been explored with regards to radiation monitoring, namely GSM [17], ZigBee [18], [19], GPRS [19] and XBee [20] amongst others. Moreover, different means of monitoring interface has been used for such intend and purpose, but not limited to webservers [21], LabVIEW [20], Java application [17] and mobile applications [13].

Therefore, in this work, the Geiger-Muller (GM) tube is utilised as it has the capability of detecting a wide range of radiation types [16], whilst the transmission of data from the sensors is made through the ESP-01 Wi-Fi module. In addition, the ThingSpeak platform used to enable the Internet of Things (IoT) module in realising the proposed system that in turn allows for the display of the radiation data detected by the sensor.

Methodology

Conceptual design

The conceptual design categorized of this study may be demarcated into three major sections, namely the radiation detection sensor system, wireless communication system and monitoring interfaces system. As for the radiation detection sensor system, the Geiger-Muller tube is utilised.

The data collected from the sensor is transmitted via wireless communication to the base station as shown in Figure 1. Upon receiving the data, the microcontroller will store the data obtained and share the information with the web interface which is accessible via the Internet. The Serial Peripheral Interfaces (SPI) is used to transmit data between the microcontroller and the sensor.

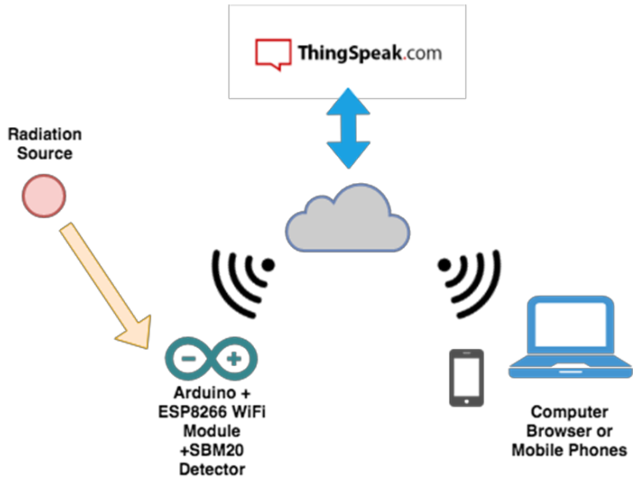

Figure 1. Overall system architecture.

This SPI employs a master-slave architecture which the master devices able to initiate and controls all communication with the slave. The wireless communication will be achieved by using ESP-01 Wi-Fi module and ThingSpeak platform as a public platform in the study.

System design

In order to develop a wireless radiation monitoring network which could achieve the desired conceptual design, the selected material and apparatus needed to develop this project are specified.

Selection of material and apparatus

The main material selected to construct the development of wireless wide area radiation monitoring network are Arduino Uno kit, Radiation Detector Arduino Compatibility DIY Kit, SBM-20 Geiger Tube, ESP-01 Wi-Fi module and AA Batteries. The basis of using Arduino kits are primarily owing to its simplicity of programming the microcontroller as well as its cost effectiveness. The Radiation Detector Arduino Compatibility DIY Kit consists of high quality silkscreened PCB together with its components to build a nuclear radiation detector. This new edition of detector kit has a high voltage electrical circuit based on the 555 timer IC.

SBM-20 Geiger tube is chosen compared to other Geiger tube based on the consideration of all the tubes specification such as sensitivity, operating voltage, type of radiation detected as well as other considerations. Moreover, it compatible with the Compatibility Kit used in the present study. The ESP-01 is used to connect the radiation data from the radiation sensor system to the internet. The ESP-01 is programmed using AT commands; when received, it replies with an acknowledgment. It can be powered up using a 3.3 Volts power source or through the regulated 3.3 V power pin in Arduino Uno. The whole system is powered by four AA batteries connected in series. This battery expected to last for 90 days of a 15-seconds data transmission interval of continuous usage.

System development

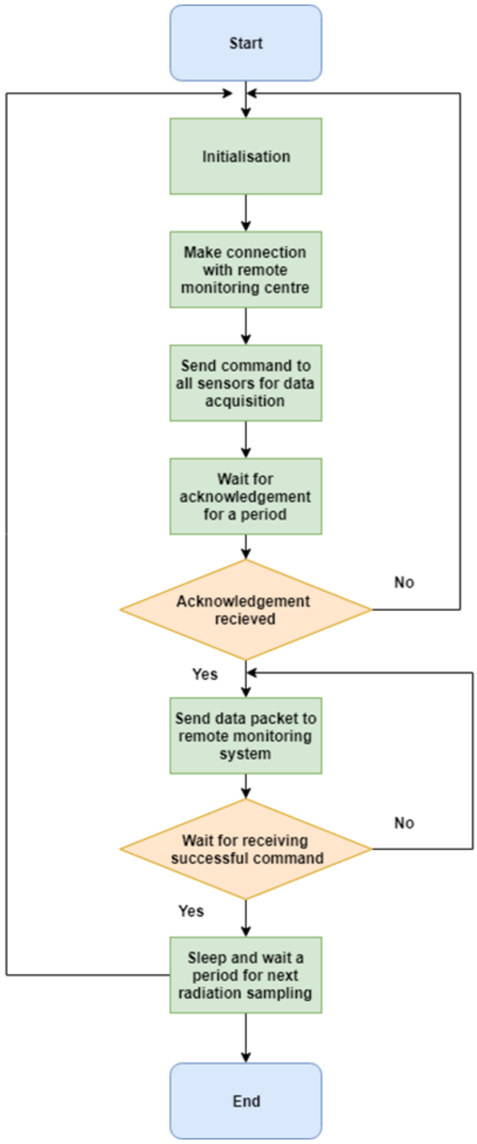

Figure 2. Flowchart of the microcontroller's execution.

The microcontroller has a pivotal role as a master in the SP interfaces. The flowchart of the microcontroller is depicted in Figure 2. Figure 3, on the other hand, illustrates the flowchart of the sensor readings and execution. The sensor nodes will receive the transmitted signal to initiate the detection sequence and send the obtained data back to the microcontroller.

The handshake protocol has also been between the microcontroller and the ESP-01 for network connection. This communication is synchronous, in which the data transmission between both devices is synchronized by a shared clock signal and the data can flow in both directions simultaneously as this communication is a full-duplex system. The flowchart of command in ESP-01 as in Figure 4.

The ThingSpeak platform provides various services exclusively targeted for building IoT applications. It offers the capabilities of a real-time data collection and visualizing the collected data in the form of charts. Moreover, it has the ability to create plugins and apps for collaborating with web services, social network as well as other APIs. The main core element of this platform is its ThingSpeak Channel. Each channel is able to store the radiation data that is sent to ThingSpeak.

System testing and configuration

The testing procedure is conducted to test the functionality of each system before it is integrated into one whole device, prior to evaluating the system in performing the wireless wide area radiation monitoring.

Radiation detector system

The testing performed for the radiation detector system are divided into two namely actual detection as well as sensor calibration. The first test is carried out to check whether the radiation detector kit together with the SBM-20 is able to perform normal detection of the background radiation as well as detecting radiation from a sealed source (in this study Cobalt-60 with an activity of 1µCi is used). The second test is the calibration of the radiation sensor system, it is done by comparing the sensor readings to the RDS-31 survey meter reading and the sealed source used is a 6110kBq activity Euperium-152.

Wireless network and monitoring interfaces system

Both of the systems were tested simultaneously due to the fact that the monitoring interfaces system requires an input data to be displayed on its platform. The arithmetic algorithms are included in the source code and the result of this data must be able to be viewed in a public platform. In the development phase of the wireless network system, the AT command in the source code is tested by uploading it in the Arduino UNO to check whether the wireless communication through the Wi-Fi module succeeded or not.

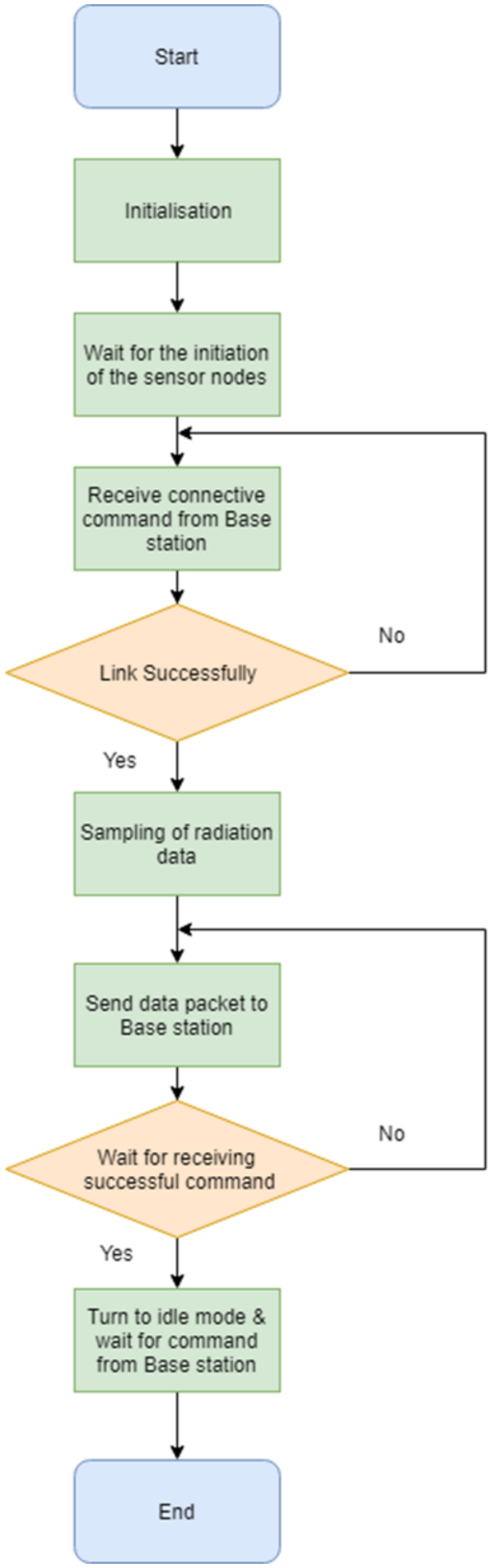

Figure 3. Flowchart of the action performed by the detector sensor.

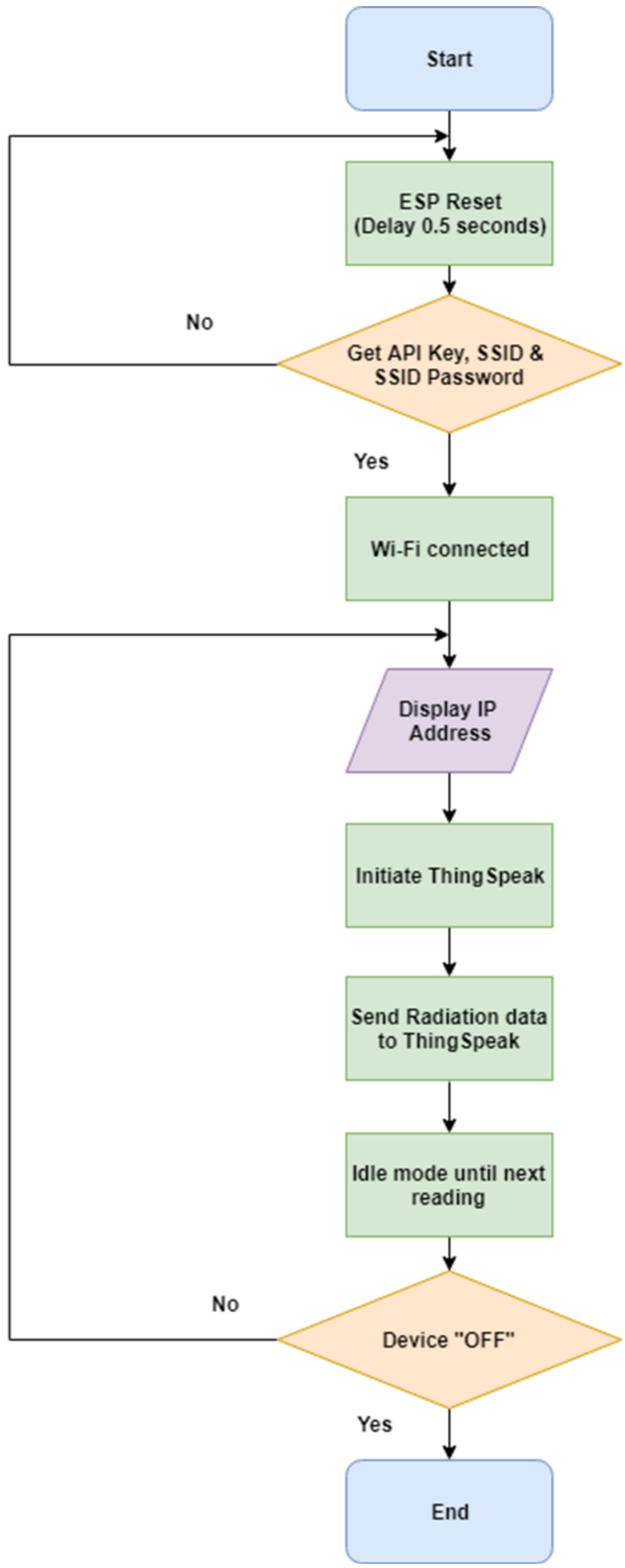

Figure 4. Flowchart of command by ESP-01.

The ThingSpeak channel that has been created during the development phase is observed to check whether the data uploaded to the cloud via the wireless network system can be received on this public platform. This channel has been set for public view and the API Keys for this channel is embedded in the source code command. The Wi-Fi SSID and password is also embedded in the source code command to initiate the connection between ThingSpeak and the cloud server.

System Integration

Upon testing the functionality of each system, the integration of the sub-systems into one device is performed. The integration of system begins by ensuring that the hardware connection between each pin is correct, the battery power supply and switch is added to the hardware component. The source code is written according to the command that is required to be executed by the device. This source code must comprise a command to enable the radiation detection, the wireless connection, and the interfacing with the ThingSpeak platform.

The hardware assembly of the system consists of two major parts namely the placement of the radiation detection kit with SBM-20 and the wiring connection of the microcontroller (Arduino UNO) and the ESP-01 which is connected through the breakout board and breadboard. The power supplies are mounted on the right side of the device and connected to a switch. The left-hand side of the device is emptied to be used for lifting and holding the device. The schematic diagram of the integrated system as in Figure 5.

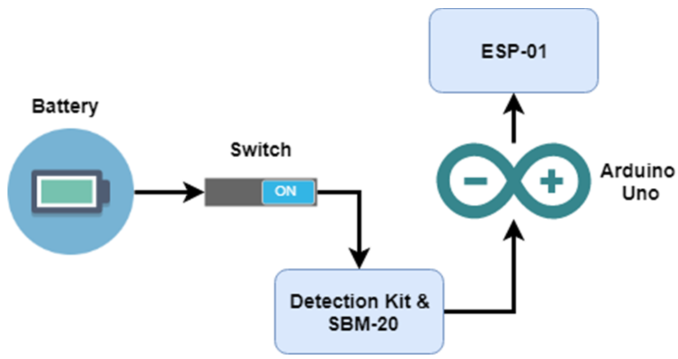

Figure 5. Schematic diagram of an integrated system.

Results and discussion

Radiation detector System

The normal functionality test is conducted upon the Geiger kit assembled with the SBM-20 detector and integrated with the Arduino UNO microcontroller. The count rate of the detector is obtained by varying the effective distance between the sealed source and the detector. The result obtained recorded in Table 1.

The maximum count rate achieved at zero effective distance and it is also noticeable that after the effective distance of 30 cm, the count rate detected resembles approximately to the background count rate which has an average value of 40 cpm. This observation, suggests that the principles of inverse-squared law is

Table 1. Result for testing of radiation detector system with Cobalt-60.

Source-Detector Distance (cm)	Count Rate (cpm) Count 1	Count 2	Count 3	Average Count Rate (cpm)
0.0	2736	2660	2732	2709
7.5	240	260	256	252
15.0	128	112	152	131
30.0	44	44	56	48

*Background Radiation: ≤40 after the effective distance beyond 30 cm

Table 2. Result for calibration of radiation detector system with Euperium-152.

Source-Detector Distance (cm)	Dose rate (μSv/hr)			Average Dose Rate (μSv/hr)		Error (%)
	Count 1	Count 2	Count 3	SBM-20	RDS-31	
0	17.28	18.51	17.28	17.69	17.71	0.1
15	2.42	2.80	2.92	2.71	2.78	2.5
30	1.19	1.16	1.19	1.18	1.09	8.3
45	0.78	0.66	0.62	0.69	0.65	6.2
60	0.48	0.43	0.43	0.45	0.32	40.6
75	0.25	0.27	0.32	0.28	0.23	21.7
90	0.32	0.27	0.18	0.26	0.21	23.8
105	0.18	0.25	0.23	0.22	0.20	10.0

applied where the amount of radiation dispersed becomes lesser as the distance increases. The detector demonstrated its functionality by providing the radiation reading.

The second test is the calibration for this system is performed afterward it's testing. This process in non-trivial as it is carried out to ensure that reasonably accurate reading is attained by the system. The readings of the sensor is compared to the results obtained by the standard survey meter, DRS-31(Mirion Technologies). Euperium-152 sealed source is used for calibration since it has the highest activity in the laboratory, i.e, 6110kBq. The result obtained recorded in Table 2.

The error of the sensor data could due to the fixed conversion rate used in the source code for this calibration test. The unit measure by the Geiger Tubes are basically the number of pulses generated and the relationship between count rate and dose rate is established through empirical calibration procedures in which the detector is exposed in a radiation field [20]. Therefore, the conversion rate from counts per minute (CPM) to milliSievert per hour (μSv/hr) for SBM-20 is 0.0057 used based in the references conversion method in Arduino Compatible Geiger Kit by the manufacturer [7].

Besides, the changes in the placement of the source between the survey meter and detector sensor system could also lead to the inconsistency of data taken. The readings will change drastically if the placement of the source is different between each effective distance of the source. The amount of reading in one system will be higher than the other, particularly when it is moved by several inches difference. This effect is noticeable especially at shorter distances.

Wireless network system and monitoring interfaces system testing

Figure 6. Serial monitor of successful data transmission.

The wireless network system and the monitoring interfaces system are tested simultaneously. The string algorithms set for two results, in which the result obtained in field 1 is twice the amount obtained in field 2. The results obtained in this test (from the serial monitor) is depicted in Figure 6.

Wireless wide area radiation monitoring network testing

The final test is carried out on the assembled device. Based on the test performed, the radiation data is able to be successfully transmitted from the sensor system to the ThingSpeak channel using Wi-Fi connection by ESP-01 in real-time as shown in Figure 7. The data that is accessible in the public platform are the radiation count per minute (cpm) and dose rate (μSv/hr). It is worth noting that the data shown in the ThingSpeak platform is identical to the one shown in the serial monitor suggesting that real-time data transfer transpires.

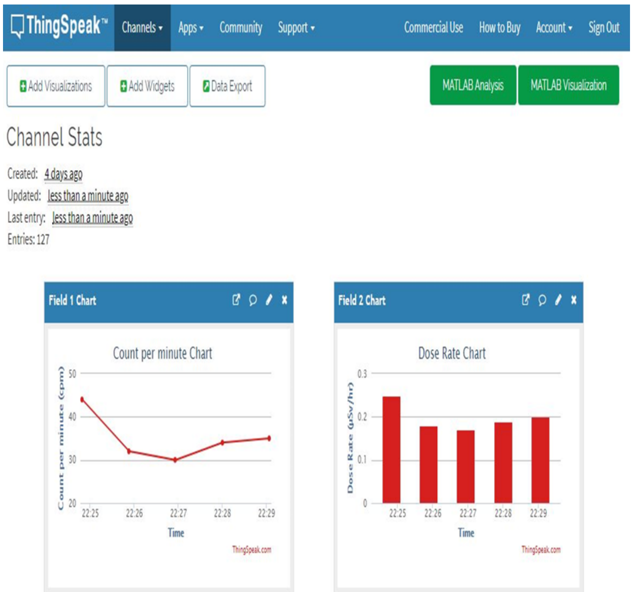

Figure 7. Public platform interfaces of wireless wide area radiation monitoring network.

Conclusion

This paper demonstrates the development of a relatively low-cost wireless radiation monitoring system. Moreover, it was shown that the SBM-20 is able to provide reasonably accurate readings of the radioactive source to a certain degree. This system is rather beneficial as it covers a wide area and is easily accessible as well as provide reliable real-time information. In addition, the present study demonstrated that through the exploitation of the IoT infrastructure, remote radiation monitoring particularly within the vicinity of a nuclear power plant and/or nuclear/radioactive material facility is possible.

Acknowledgement

The authors would like to acknowledge Universiti Teknologi Malaysia for supporting this project.

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