Developing a Remote Mapping Device for Radiation Monitoring and Investigation

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Abstract. Over the last few years, the demand for unmanned system has been raised for rapid and safe response to some nuclear disaster like the Fukushima accident or the dispersal of radioactive materials caused by unauthorized acts. Typically, a gamma or neutron detector mounted on a drone is used for radiation surveillance but it suffers from lower detection efficiency related to short operation time of a drone and allowable altitude. In order to acquire the proper data, it is required to place a detector as close to the source term as possible and maximize the detection time. Therefore, the present authors have designed a radiation mapping device named the gamma probe consisting of a CsI sensor, electronics for wireless data transmission, and software. A parachute is also designed and optimized to get into difficult to reach. The parachute is automatically detached to keep the position when the probe is completely landed. Electronics consist of 3 circuit boards used for detector operation, probe control and data transmission. Considering the payload capacity of a drone, totally 8 probes are loaded on a drone and spread out over the suspicious area. The probe is then collect radiological information for 15 min to locate and quantify gamma radiation level within area. Based on the geological and radiological information collected by each probe, the exact position of the source can be also calculated since the strength of radiation signals is proportionally changed by the distance from the source. The entire system is controlled by the O/S software developed by the present authors. The future step will be to try to optimize the experimental parameters in order to improve performance and accuracy.

KEYWORDS: Disaster Response, Unmanned System, Radiation Mapping

1 INTRODUCTION

Unmanned Aerial Vehicle(UAV) or drone have been studied for using various application such as transport, security, and etc. Especially, UAV shows high accessibility so that the geological and radiological 3D mapping data can be acquired easily. Also, UAV is possible to scan the unknown-contaminated area by the unwanted dispersion of radioactive materials. After the Fukushima accident, the research demands for UAV system has increased for radiation monitoring and investigation.

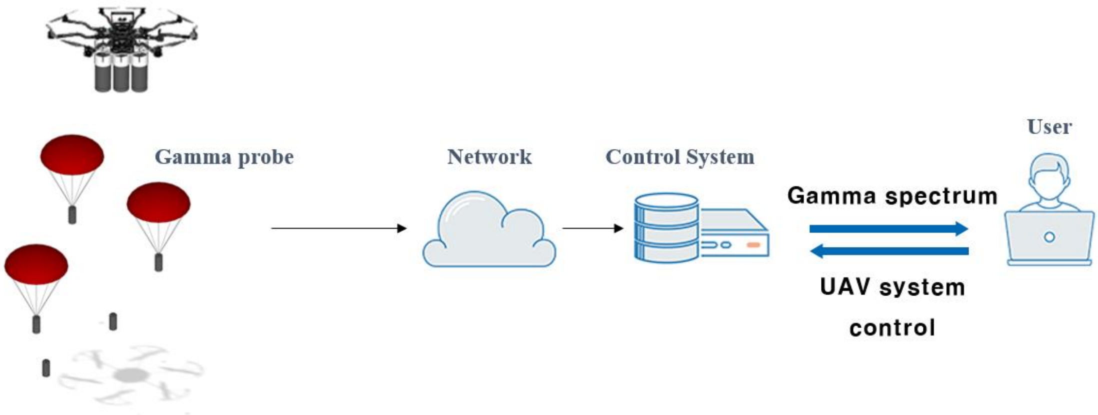
A gamma or neutron detector mounted on drone is widely used for radiation monitoring in suspicious areas. However, drone with mounted detector suffers from lower detection efficiency because of short operation time and low allowable altitude. In order to acquire the proper data, it is required to place a detector as close to the radiation source as possible and to maximize the detection time. Therefore, the present authors have designed a radiation mapping device named the gamma probe consisting of a CsI sensor, electronics, and software.

2 MATERIALS & METHODS

2.1 Concept of unmanned gamma probe system

The gamma probe system operates with drone for preventing human exposure in high-radiation areas. The drone that is mounted with the gamma probe moves to the target point and drops the gamma probe. The dropped gamma probe transmits the position-coordinate information and then starts to measure the gamma rays in target point. After the set time has passed, measured gamma spectrum is also transmitted to the user. The radiological map can be obtained with some calculation based on the position-coordinate information and gamma counts data.

Figure 1: The Schematic design of gamma probe systems



The operation time of the drone depends on the take-off weight. So the lighter weight of the mounted gamma probe, the longer drone can fly. Therefore, the design of gamma probe is focused on miniaturization for transporting multiple probes at once. As shown in Figure 2, eight gamma probes are used to carry out mission of radiation measurements. Each probe has 190mm long and 80mm in diameter housing and it is made of lightweight materials such as plastic (about 600g).

Figure 2: The schematic design of gamma probe

Three different functional plastic circuit boards are used for signal processing: detector operation, probe control and data transmission. When probes are spread out over the suspicious area, the altitude of drone is more than 10 meters. Thus, a parachute is also designed and optimized to get into difficult to reach safely. The parachute is automatically detached to keep the position when the probe is completely landed. Also, pads, which consisted of soft substances, were attached to the underside of the probe in order to prevent the impact from the ground. The probe is then collect radiological information for set time (typically 15 minute) and quantifies gamma radiation level within the area.

Distributed radiation detectors such as probes have advantages over drones with combined radiation detectors. The first is the measurement time. Accurate radiation information can be obtained based on long-time measured information in the area. It is difficult to take long time measurement with a flying drone. The second is the measurement distance. Since the probe is located on the ground and measures the radiation dose, it is highly efficient compared to the measurement of the drone.

2.2 System Design

Based on the concept of the system, the prototype has been designed, built and tested. The system consists of radiation sensor, related electronics and user interface.

2.2.1 Radiation detection sensor

The gamma-ray energy spectrum can be achieved by the direct and indirect methods depending on how the incident gamma-ray is converted into an electrical signal. Although the characteristics of the semiconductor sensor in the direct detection method have high energy resolution compared with the indirect detection method, the scintillation crystal is preferred because typically high Z-number of materials are used and no cooling is needed. In this reason, the performance of two different indirect scintillator, Thallium doped Caesium Iodide (CsI(Tl)) and Cerium doped Gadolinium Aluminium Gallium Garnet (GAGG(Ce)), were compared as a radiation detector[1]. The Table 1 and 2 show the physical characteristics of CsI(Tl) and GAGG scintillator: melting point, Light yield, decay time, and maximum emission wavelength.

Table 1: Characteristics of CsI(Tl) scintillation

Properties	Value	Properties	Value
Density [g/cm^3]	4.51	Wavelength of emission max. [nm]	550
Melting point [K]	894	Lower wavelength cut off [nm]	320
Thermal expansion coefficient[C^{-1}]	54×10^{-6}	Refractive index@emission max.	1.79
Cleavage plane	None	Primary decay time [ns]	1000
Hardness [Mohs]	2	Light yield [photons/keVγ]	54

Table 2: Characteristics of GAGG scintillation

Properties	Value	Properties	Value
Density [g/cm^3]	6.63	Wavelength of emission max. [nm]	520
Melting point [K]	1850	Lower wavelength cut off [nm]	475
Radiation length [cm]	1.1	Refractive index@emission max.	1.9
Cleavage plane	None	Decay time [ns]	450-150
Hardness [Mohs]	8	Light yield [photons/keVγ]	40-60

Table 3: Energy resolution of scintillation detector [1]

Gamma-ray energy [MeV]		^{133}Ba	^{22}Na	^{137}Cs	^{60}Co	
		0.356	0.511	0.662	1.17	1.33
Scintillation detectors	Ce:GAGG	13.5 %	6.9 %	5.8 %	-	2.3 %
	CsI(Tl)	24.8 %	11.5 %	10.2 %	-	-

A cost is one of the most important factor for design the device. Although the light yield that the photon generation per unit energy of both materials is similar and the energy resolution of GAGG(Ce)'s performance is better than CsI(Tl) (Table 3), CsI(Tl) is better comparing GAGG(Ce) for the probe's scintillator because of the price. Typically, GAGG(Ce) is about five times expensive than CsI(Tl). In addition, the probe spread out in contaminated area cannot get back and re-use. In order words, it is disposable.

The Figure 3 shows the radiation sensor module with the CsI(Tl) scintillator of 12.5×12.5×20 mm. It has a photodiode, a preamplifier and the bias voltage is 33V. The full size of module is 35×28×15 mm so that it is suitable for use as a small instrument.

Figure 3: CsI(Tl) radiation sensor module

(a) upper (b) bottom (c) side

2.2.2 Electronics

The interior of probe consists of a gamma-ray detector, a driver circuit, and a GNSS receiver. The probe's electronic circuit and firmware send the radiation and location information to main control equipment posited on a safe area. Because an internal battery was used, electronic circuit and communication modem was designed and selected to minimize a power consumption.

The driver circuit consists of a CsI(Tl) board, a controller board, and an interface board. CsI(Tl) board has a 1024 channel multichannel analyzer, an amplifier, and a A/D converter. It converts and amplifies incident radiation into an electrical signal and outputs it as a gamma-ray counts value. The controller board consists of a microcontroller, a memory, a GPS receiver, a LoRa modem, and an LED interface. It is designed for data communication primarily. The interface board supplies the electric power to each circuit and has a solenoid actuator, an accelerometer, and a remote sensing sensor. The solenoid actuator is a function for the drop of the gamma probe and is operated by a drop command received from the controller board. The CsI(Tl) driven PCB, controller PCB, and interface PCB are assembled in a stacked by using spacers and mounted within the probe housing as shown below Figure 4.

Figure 4: Printed circuit board of gamma probe

Wireless communication signal has been decided for remote monitoring in an unknown ground without geological/radiological information in real-time. Common types of wireless communication signals including Bluetooth, Wifi, LTE, and LoRa was discussed. Table 1 shows the characteristics of representative wireless communications.

Table 4: Characteristics of wireless communication

	Bluetooth	Wifi	LTE	LoRa
Typical Range	20 m	50 m	2 km	5-10 km
Frequency	2.4 GHz	5 GHz	1 MHz	867-928 MHz
Transmission speed	1.0-2.1 Mbps	2-54 Mbps	1 Mbps	0.2-50 kbps
Power consumption / Battery life	1-30 mW	50-200 mW	About 10-20 years	About 10 years
Standardization	IEEE 802.15.1	IEEE 802.11b.g	3GPP Release12	Non standard
Connected time	≥ 100 ms	≥ 10 ms	1 ms	≥ 400 ms

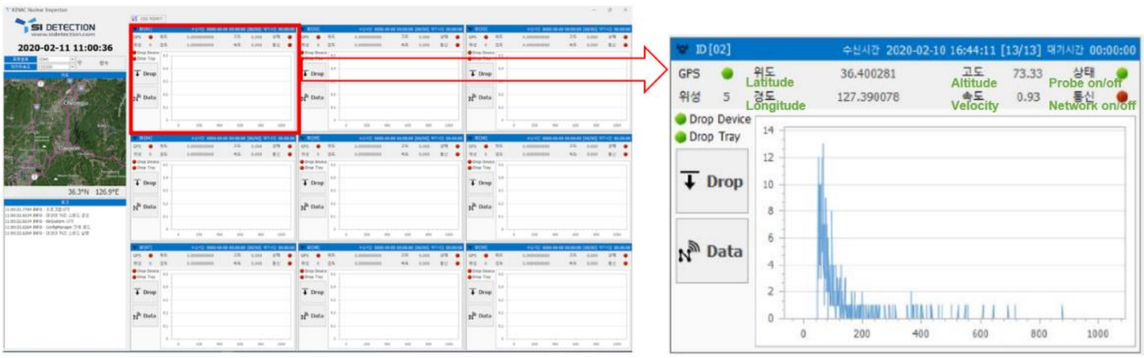
The wireless communication methods are reviewed. Bluetooth and Wifi are not suitable because the gamma probe is designed for long-distance communication. In addition, LTE has the disadvantage that needs access point and high expense.

LoRa communication has a low speed, but the long range and low power communication protocol. LoRa has the advantage of running an isolated or private network on a farm or in a city. Actually, it is ideal for sensors that only seldom send a value, like a soil moisture sensor sending its measurements every 10 minutes, or a water trough alarming when it is empty [2]. Also, as a part of the decision support system for nuclear emergency response, a prototype of mobile radiation measurement system has been developed [3]. On the other hand, the interference will occur at LoRa because it uses a non-licensed frequency. And, LoRa communication can be used for applications requiring low data rate limited to 27 kbps. As considering power consumption and communication range, LoRa communication modem was finally selected.

2.3 User Interface

The program is designed to control up to nine probes and receive a probe status, a GPS data, and a gamma spectrum data. The Figure 3 shows the graphic user interface of the data acquisition program that the main screen is designed to display nine pieces of equipment. At the top of the screen, an ID is displayed to distinguish the gamma probes, and the last data reception time of the equipment can be checked. Additionally, the screen displays a GPS status, a latitude, a longitude, an altitude, a speed of gamma probe, and a number of satellites. If the equipment is connected, the Network on/off is green at the right side of the window.

Figure 3: Software GUI & main window



For dropping the gamma probe on the drone, click the Drop button to deliver the drop command to the equipment, and the Drop Device displays green if the drop command is normally sent and red when not sent. Besides, if commands are delivered normally to Drop Tray equipment, they display green and red when not delivered. The dropped gamma probe could detect the gamma ray and then radiation spectrum data is automatically transmitted to the user. It is also possible to obtain the gamma spectrum manually by clicking the data button.

3 RESULTS

The unmanned gamma probe system has been built for finding out hidden radioactive materials such as ^{137}Cs and ^{60}Co. Each probe is connected to the parachute that 90cm in diameter. It contains the radiation detection sensor, various circuit boards, wireless data transmission system that is assembled intensively in the interior space to minimize the volume of gamma probe. As shown in Figure 4, eight gamma probes have been built for radiation measurements and it is designed to check the condition of gamma probe. There are three LED that can check the status of a GPS connection, a MCA, and a remaining battery. It is possible to determine whether the probe can operate normally.

The performance of developed gamma probe was tested. The transmission of GPS information and gamma probe drop is successfully carried out. And, gamma-ray detection test was performed for ^{137}Cs and ^{60}Co sources. After the detection, gamma probe transmits the gamma spectrum to software and the data was saved in ‘CSV’ format. Table 5 and 6 show the gamma-ray spectrum of ^{137}Cs and ^{60}Co present using a radiation analysis program. The gamma energy peak could be clearly identified and the energy resolution is approximately 10% in FWHM.

Figure 4: The developed gamma probe

Figure 5: ^{137}Cs gamma-ray spectrum

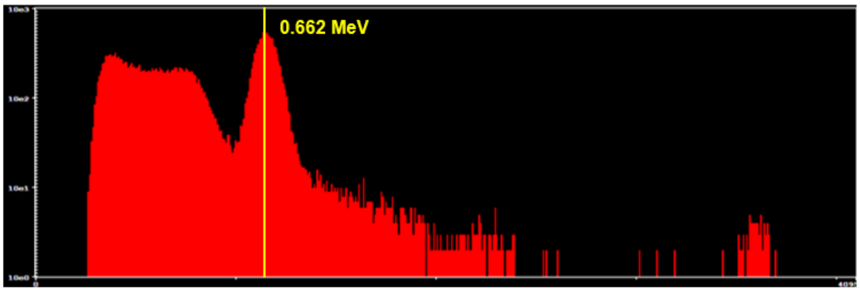
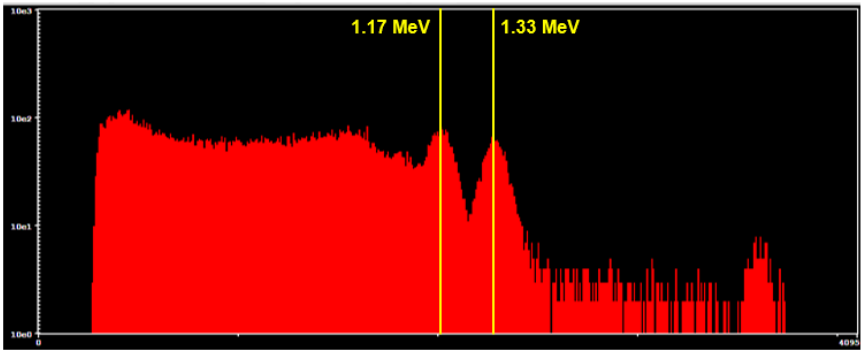


Figure 6: ^{60}Co gamma-ray spectrum



4 CONCLUSION

In this study, the unmanned gamma probe system is developed. The gamma probe is initially developed for finding out suspicious radiation material. The CsI(Tl) based signal processing and telecommunication electronic system was designed and fabricated for prototype testing.

In the further studies, the exact position of the source can be calculated based on the geological and radiological information collected by each probe, since the strength of radiation signals is proportionally changed by the distance from the source. The future step will be to try to optimize the experimental parameters in order to improve the probe's performance and accuracy.

The gamma probe is expected to be available in various national security areas, such as a detection for nuclear experiments, a unauthorized activities, and a training in response to a radioactive accident. In addition, it will be available for monitoring the decontamination, dismantling of nuclear facilities to verify the presence of radioactive contamination.

5 ACKNOWLEDGEMENTS

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