Wireless underwater SiPM-based gamma spectroscopy for real-time marine radioactivity monitoring

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1. Introduction

Marine radioactivity monitoring is getting important to relieve public anxiety and to take immediate action for unexpected nuclear accidents. Currently, real-time marine radioactivity monitoring is conducted using gamma detectors (e.g. NaI(Tl) coupled with PMT) installed at specific sites in coastal area. However, there are several limitations in current site-specific gamma monitoring systems. First, gamma-ray loses most of its energy within water environment, so with the site-specific system, it is hard to identify contaminated area. Also, ocean environment has difficulties in supplying stable power and data communication. Hence, most of gamma monitoring systems are installed in coastal area or on ship to have stable power supply and wired data communication or LTE-based wireless communication.

Hence, we come up with necessities mobile battery-powered gamma spectrometry system that can conduct active marine radioactivity monitoring. We developed SiPM-based gamma spectroscopy with wireless data communication. The suggested mobile gamma spectroscopy can be used as stand-alone or combined with unmanned vehicles to conduct real-time active radiation monitoring and identify contaminated area. The developed system was tested in underwater and real-sea environment to evaluate its performance.

2. Methods and Results

2.1 SiPM-based mobile gamma spectroscopy

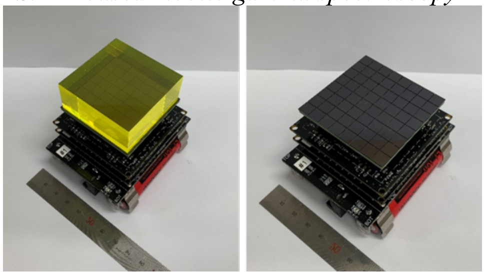

Fig. 1. In-house developed mobile gamma spectroscopy using Ce:GAGG scintillation crystal coupled with SiPM.

In this study, we used SiPM-based gamma spectroscopy to develop a real-time marine radioactivity monitoring system. Key features of the in-house developed mobile gamma spectroscopy are compactness and battery-powered (low-power) system. To have a compact geometry, high sensitivity 48×48×20 mm^3 Ce:GAGG crystal (EPIC, China) was coupled with an 8×8 SiPM array (OnSemi, USA). For the low-power battery operation, front-end electronics and low-power MCU-based data acquisition circuits were developed [1] and low-power wireless data communication was implemented. Two wireless data communication schemes were implemented: ZigBee and LoRa. ZigBee is well-known as low-power short-range fast network, so real-time event-by-event data communication configuration was implemented. On the other hand, LoRa is well-known as low-power wide-area network, so cumulated data communication scheme, which sendins cumulated data at the end of acquisition, was implemented. Table 1 summarizes specifications of the developed system.

Table I: Specifications of the developed SiPM-based mobile gamma spectroscopy

	Specifications
Scintillation crystal	Ce:GAGG 48×48×20 mm^3
Photosensor	8×8 SiPM array (ArrayJ-60035-64P-PCB, OnSemi, USA)
Detector weight	560 g (including battery)
Detector size	6.5×6.5×8 cm^3
Energy range	20 keV – 2 MeV
Energy resolution	8.75 ±0.21%
Operation time	Up to 24h
Data communication	Real time: ZigBee (2.4 GHz) Cumulated: LoRa (915 MHz)
Etc.	Temperature, water/air pressure, and altitude sensor

2.2 Underwater performance evaluation

To evaluate underwater performance of the developed system, we conducted experiments in a large water tank. All experiments were held inside the 35×20×9 m^3 sized water tank located at Underwater Robot Test Center of the Korea Institute of Ocean Science and Technology (KIOST) in Pohang.

2.2.1 Underwater wireless data communication

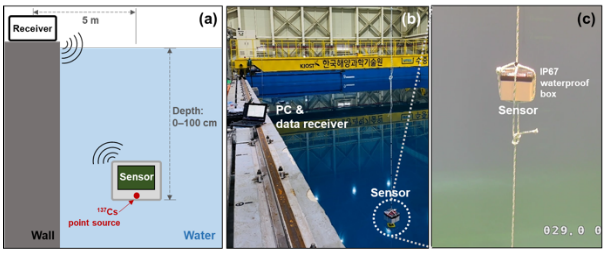

Fig. 2. Underwater wireless data communication experiments.

Unlike terrestrial environment, it is very challenging to utilize wireless data communication inside the water environment. In this study, we evaluated underwater data communication test for the developed sensor. The SiPM-based gamma sensor was enclosed within the IP67 waterproof box and placed inside the water tank. The box was tied up to the crane to finely tune the depth of the sensor inside the water. The depth of the sensor ranged from 0 cm to 100 cm with a 20 cm step size and the 3.7 kBq ^{137}Cs point source attached to the detector as shown in Fig. 2. Measurement was conducted for 15 min at different water depths. For ZigBee configuration, communication success rate was evaluated to see the real-time communication performance. For LoRa configuration, since 15 min cumulated spectra was sent at once at the end of acquisition, success or failure was evaluated to see the communication performance.

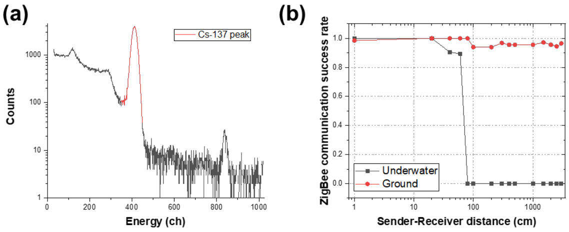

Fig. 3. (a) Energy spectra acquired at 100 cm water depth using LoRa communication. (b) ZigBee communication success rate in underwater.

As a result of underwater communication test, LoRa showed successful data communication up to 100 cm water depth. Fig. 3(a) shows energy spectra acquired at 100 cm underwater environment and we successfully acquired the energy spectra. In case of ZigBee, we observed high communication success rate ranging from 1 to 0.89 until 60 cm water depth. However, once the sensor was located deeper than 80 cm, we were not able to acquire any signal transmission. (Fig. 3(b))

2.2.1 Underwater detector performance

To evaluate detector performance inside water, the sensor was located at 20 cm water depth. As shown in Fig. 4, the 3.7 kBq ^{137}Cs point source was tied up to the crane to modify the source-to-sensor distance from 0 cm to 100 cm with a 20 cm step size. Please note that the point source and the sensor was not aligned at the center due to the interference between the waterproof box and the rope. Measurement was conducted for 15 min at different source-to-sensor distance.

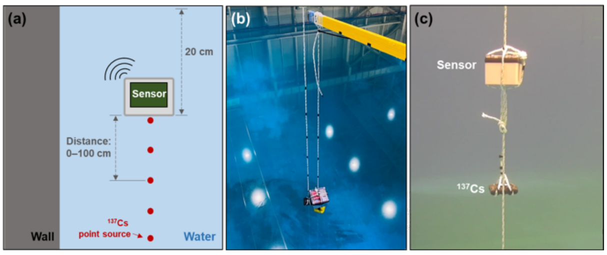

Fig. 4. Underwater detector performance experiments.

Fig. 5 shows results of underwater detector performance. As shown in Fig.5 (a), most of low-energy gamma went through Compton scattering as expected. We were able to detect low-activity source (3.7 kBq) within 20 cm source-to-sensor distance. However, once source and sensor placed farther than 20 cm, it was challenging to identify the ^{137}Cs source.

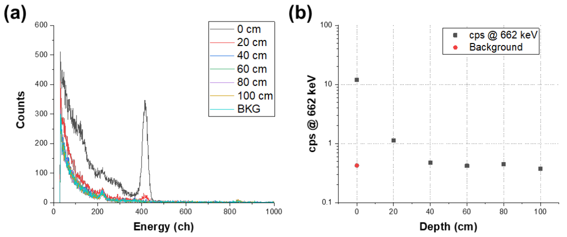

Fig. 5. (a) Energy spectra at different source-to-sensor distances. (b) Count rate at 662 keV at different source depth.

2.3 Real-sea source tracking experiments

Moreover, we conducted experiments in real-sea environment. The developed radiation sensor was combined with unmanned surface vehicle (USV) developed by KIOST that allows automated and manual driving in water with speed up to 16 km/h. The 3.07 MBq ^{137}Cs point source was hidden near the land (red point in Fig. 6). The USV combined with the radiation sensor was placed at 10 m apart from the source and started source tracking to see the potential of our developed real-time radioactivity monitoring system. The USV traveled following the line in Fig. 6. At each point (0.5, 2, 3, 5, and 10 m from the source), measurement was conducted for 5 min and energy spectra was acquired. As a result, once the USV moved closer to the source about 3 m, the sensor successfully detected ^{137}Cs peak. Moving closer to the source, we detected higher count rate in ^{137}Cs peak.

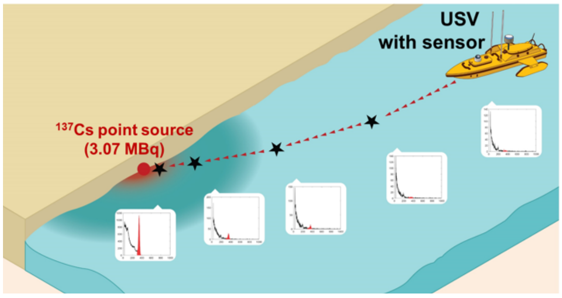

Fig. 6. Real-sea source tracking experiments.

3. Conclusions

In this study, we developed mobile sensor for marine radioactivity monitoring. The developed sensor allows low-power operation (~24h using battery), has small and compact geometry (<600g, 6.5x6.5x8 cm^3), and offers wireless data communication (real-time or cumulated data transfer). Underwater performance was evaluated. Finally, we have successfully tested potential of the real-time marine radioactivity monitoring system using our developed mobile sensor.

REFERENCES

[1] J. Lee, M. S. Lee, M. Jang, and J. M. Lim, Comparison of Arduino Nano and Due processors for time-based data acquisition for low-cost mobile radiation detection system, Journal of Instrumentation, Vol 17, P03015.