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Unmanned Aircraft Based Gamma Spectrometry System for Radiological Surveillance

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Summary:

In the framework of the European “Preparedness” project, PTB is developing a spectrometer based dosimetric system that can be operated while being attached to an unmanned aerial vehicle (UAV). Built around 1.5" $CeBr_3$ scintillation detector, the radiation monitoring system records spectra alongside with temperature and flight telemetry at 0.5 Hz acquisition rate and transmits these data to a ground station where an algorithm calculates dose rates and activities. The presented aerial test results illustrate system’s ability to precisely target a source and provide a good estimation of its activity.

Keywords: Radiation monitoring, spectro-dosemeter, cerium bromide, UAV, "Preparedness"

Introduction

In the aftermath of a nuclear or radiologogical event, the metrologically sound data on the ground and air contamination is of major importance for decision-makers to manage the emergency response in a timely and adequate manner. As an example, following the Fukushima Daiichi nuclear accident, weeks had gone till the first detailed radiation distribution map was available. A significant problem in tracking radioactive release was that the majority of radiation monitoring stations on the plant site were disabled by the tsunami, and this absence of reliable local data amplified the evacuation burden in the region. This disaster uncovered the lack of tools in the radiation protection field necessary to assess the radiological situation in time-resolved but accurate way.

The airborne radiation monitoring is the key to the fast contamination assessment following a radiological event. The conventional way involves deploying manned helicopters or small airplanes. Whilst being good for the large-scale evaluation of the radiological situation, this approach bears the problems of crew exposure and low spatial resolution due to the high altitude and flight speed, thus over-averaging terrain features (trees, rooftops, etc.) and, therefore, the contamination profile. The use of unmanned airborne monitoring systems offers the benefits of the high-resolution aerial measurements, especially in the areas otherwise inaccessible by big aircraft (e.g. NPP vicinity), and the operating personnel protection, as devices can be controlled from a safe distance.

Equipment

Nowadays, it is hard to catch the booming drone industry which brings regular advances in UAV technology, so we have designed a radiation monitoring system as a standalone device that can be mounted onto any drone with sufficient payload capacity. Thus, being independent of the carrier, the spectrometer is accompanied by a RasPiGNSS positioning module, SF11C laser altimeter, MS5607 barometer (altitude redundancy sensor) and a 2.4 GHz XBee transceiver. The spectrometric module resides in a 3D-printed housing and consist of 1.5" $CeBr_3$ scintillator with a photomultiplier tube readout, compact 120 MS/s BPI base and PT1000 platinum temperature sensor. The aluminum plate that provides device-mounting points and supports remaining system components is fixed on top of the detector housing. The brain of the system is a Raspberry Pi Model 3B microcontroller. The system is powered with a 5200 mA Li-ion battery which gives about 4 hours of operational time. The device weighs 1.5 kg; its dimensions in cm are H23 x L20 x W17 (see Fig. 1). The ground station, a laptop with another 2.4 GHz XBee transceiver, establishes peer-to-peer communication with the monitoring system and receives data every 2 seconds. The acquisition and control software is written in Python 3.5.

Method

The detector is a spectro-dosemeter, meaning it matches or even surpasses the accuracy of the best modern dosemeters while having the advantage of providing spectral information.

Fig. 1. The radiation monitoring system mounted onto a DJI M600P drone.

In environmental radiation monitoring, the measured dosimetric quantity is the ambient dose equivalent $H^*(10)$. Here, it is derived using the following formula:

$$H^*(10) = \sum v_i N_i \qquad (1)$$

where N_i is the number of counts in channel i and v_i is the conversion coefficient for the mean energy of channel i. The conversion coefficients were calculated using PTB reference irradiation fields. For energy bands, where quasi-monoenergetic γ-ray sources were unavailable, coefficients were derived from Monte Carlo simulation in Geant4 radiation transport code. The method of the spectrum to dose conversion without deconvolution is thoroughly described in [1]. Practically, a spectrum is not grouped into energy bands, but the energy dependence of the conversion coefficients is approximated with a function [2]. This way, the uncertainties of fit parameters are propagated into uncertainties of conversion coefficients.

The algorithm of source location and activity restoration from the aerial data goes as follows:

1) From the dose rate at a flight altitude $\dot{H}^*(10)$ subtract the background dose rate $\dot{H}^*(10)_{\mathrm{bg}}$ which can be measured separately or taken from mission periphery data points;

$$\dot{H}^*(10)_{\mathrm{src}} = \dot{H}^*(10) - \dot{H}^*(10)_{\mathrm{bg}} \qquad (2)$$

2) With the source contribution $\dot{H}^*(10)_{\mathrm{src}}$ left, define a surface activity mesh and calculate response factors f_{ij} at grid points:

$$\dot{H}^*(10)_{\mathrm{src}} = \Gamma A/r^2 \rightarrow f_{ij} = \Gamma/r^2 \qquad (3)$$

where Γ is the isotope dose rate constant and r is the source-detector distance;

3) With the matrix of response factors F, source dose rate vector $\dot{\mathbf{H}}$ and surface activity vector $\mathbf{A}$, the general equation is:

$$F\mathbf{A} = \dot{\mathbf{H}} \qquad (4)$$

To recover the activity vector, the optimization problem with regularization must be solved as detailed in [3].

Results

Within the scope of the “Preparedness” project, an unmanned aircraft systems intercomparison exercise was carried out at the aerial site in Mollerussa, Spain. While the complete results will be published elsewhere, we present here a single scenario with the localization of a ^{137}Cs point source with an activity of 346 MBq. The flight was performed at a 20 m altitude with a speed of 2 m/s and the line spacing of 20 m. Fig. 2 depicts the $\dot{H}^*(10)_{\mathrm{src}}$ distribution at a flight altitude. The circular pattern of dose rate values clearly indicates that a point source has been detected, and the responsible isotope can be determined from the spectrum. To find the precise location and activity of the source, the eq. (4) was solved. The restored position is just 3.1 m far from the origin which is incredibly accurate considering that drone traveled 4 m per measurement; the restored activity is (398 ± 27) MBq which encompasses the true value within 2 standard deviations.

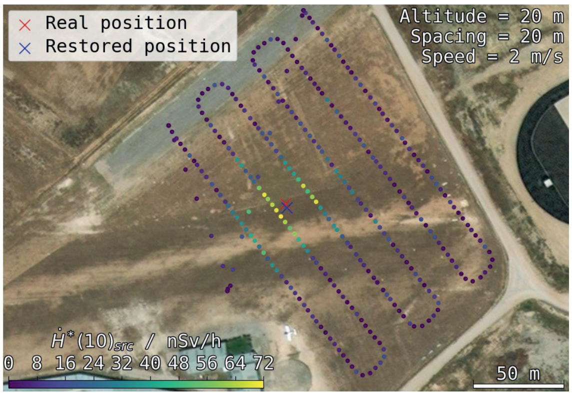

Fig. 2. Increase in ambient dose equivalent rate at a flight altitude during 346 MBq ^{137}Cs point source localization mission; source position is cross marked.

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