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UAV-based radiation sensor system optimization

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1. Introduction

Unmanned aerial vehicles (UAVs) provide an efficient means of remote sensing environments where people are not accessible to conventional aircraft due to risk or accessibility issues After the Fukushima Daiichi nuclear accident in 2011, a special effort was made to use UAV internationally to monitor nuclear and radiological emergencies. Previous research has adopted several types of UAV and radiation sensors with different altitude and speed ranges, and proposed various mapping and path finding algorithms and data management systems. To optimize a UAV-based radiation sensor system with other aspects, it is necessary to combine the appropriate UAV and sensor components by understanding their nature, physics, and advantages and disadvantages in relation to the mission's objectives. Therefore, in this study, we develop an optimization problem that can design UAV-based system intuitively after quantitative analysis of each system.

2. Methods and Results

2.1 Considerations for optimal system design

We have identified many previously proposed UAV-based radiation monitoring systems. When choosing the types of UAV and radiation sensors, the diversity among the proposed systems should be compared, quantified and deciding how to optimize the system design for specific purposes. The optimization scope was set as gamma-ray spectrometer systems, because they can identify and quantify a large number of isotopes, and provide critical decision criteria for all types of emergency survey missions. In that respect, other significant sensor types such as neutron detector and GM counter are not considered in our optimization problem.

2.2 Types and geometry of sensor

As shown in Fig. 1 and Table I, each sensor material has different physical characteristics. Each scintillator or semiconductor material has different light yields or electron-hole pairs interacting with gamma radiation, which means that different optical signals and corresponding counts are sent to the detector. Among received counts in the detector, the photopeak count of the entire gamma ray energy spectrum is dependent on the product of the density (ρ) and the mass photoelectron absorption coefficient [2]. As the thickness of the sensor material increases, photopeak counts exponentially increases, where radiation intensity decreases exponentially by radiation absorption [3].

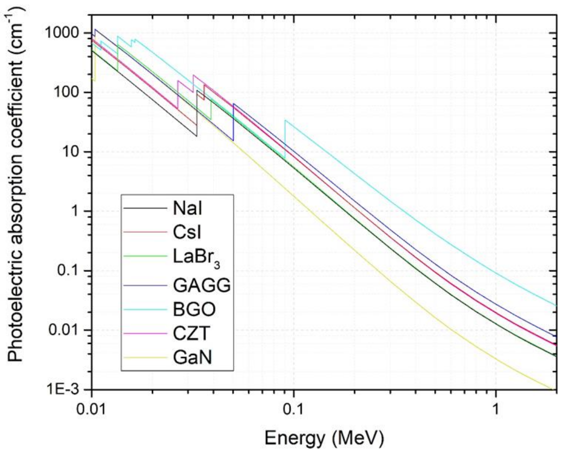

Fig. 1. Photoelectric absorption coefficient of various types of sensor materials, as a function of energy [1, 2].

Table I: Light yield for various types of sensor materials [1].

Type	Light yield [or electron-hole pair] (#/keV) [3]
NaI	38
CsI	54
$LaBr_3$	63
GAGG	50

2.3 Flight altitude and speed

Higher flight altitudes are useful for measuring a wider range of contaminated areas in a short time, but the intensity of incident radiation is reduced geometrically. For example, for a point source, the intensity of the incident radiation decreases as the distance between the sensor and the light source increases by the inverse square law [3]. For a uniformly distributed source, the geometric efficiency is slightly higher than the spatial efficiency of the point source, where the larger area of the emitted source compensates for the loss of incident radiation.

The flight velocity of a UAV affects the MDA because of its relationship to the counting time. The counting time can be defined as the effective diameter of the distributed source for the flight velocity of the

UAV. To calculate the effective diameter of a distributed source, the effective range R_{eff} was defined as the distance experiencing 99.7% attenuation. Then, as shown in Fig. 2, the Pythagorean relationship between the effective range and flight altitude can provide a value for the effective diameter.

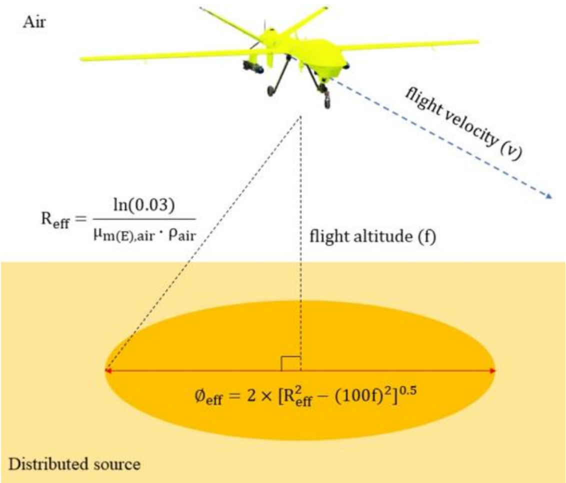

Fig. 2. Relation among effective range, diameter, and flight altitude in case of uniformly distributed source [1].

2.4 Power consumption

A large amount of scintillators contributes to an increase in the photopeak counts while an expanded payload reduces the maximum range or velocity of UAVs. In addition, the speed of the UAVs itself can affect the maximum range by varying the power consumption. Therefore, the UAV and radiation sensor types should be carefully selected and optimized in addition to the target MDA to successfully perform the task for a specified amount of time. In order to quantify relation between power consumption, velocity, and payload, the Lorenz's scaling equations of power requirements was utilized for both crewed and unmanned vehicles with various power suppliers based on actual data [5].

2.5 Definition of optimization problem

The FOM formula can be used, after determining the relevant constraints for a particular survey mission, we evaluate whether the system design has been optimized by changing parameters such as the velocity of the UAV and the geometry of the radiation sensor. Fig. 3 shows a flowchart for optimization of UAV-based radiation sensor system. The objective function can be one of a number of UAVs, system design costs, or constraints.

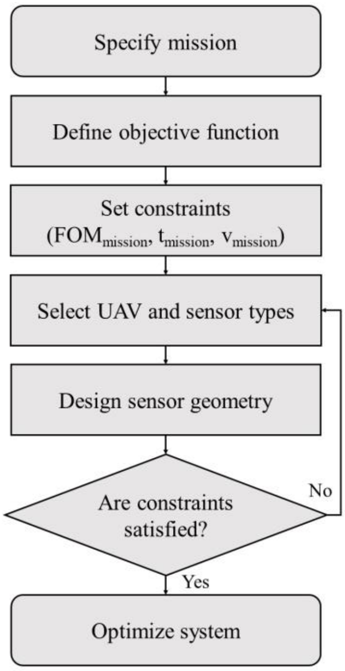

Fig. 3. Flowchart for optimization of UAV-based radiation sensor system [1].

3. Conclusions

A new FOM formula and the other constraints for optimizing systems was proposed to quantitatively analyze various system designs previously suggested and match each system one another, which can describe the interaction between the parameters of the UAV and the radiation sensor. For example, a larger radiation sensor improves photoelectron efficiency, but a mass increase negatively affects UAV durability. Similarly, fast flight speeds and high flight altitudes are favored for wide-ranging monitoring, but these factors reduce MDA. The proposed optimization problem with quantitative FOM formulas can provide an efficient way to evaluate system performance for various tasks without field testing.

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