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Evaluation of Unmanned Aerial Vehicles for Radiation Detection

Introduction

The use of unmanned aerial vehicles (UAV) has greatly expanded in the last several years. With the advancements in technology as well as the reduction in costs, potential applications are becoming more accessible.

UAVs present advantages as well as challenges. Although limited in payload capacity and flying time, the ability to easily access hazardous areas without endangering personnel, such as first responders, presents numerous applications for this technology. Some of the uses envisioned include threat detection, location, and identification from catastrophic events such as nuclear or chemical releases. This technology could enable a response team to:

- Quickly set up an operational center near a release site but outside the danger zone.
- Send one or more UAVs outfitted with appropriate detection equipment into the danger zone, with the benefit of being able to access virtually any area (no roads required).
- Scan the area for radiation or chemical signals and transmit the results in real-time to the operational center.
- Process the data received to determine the location, identify the threat, and determine the severity of the threat.

The ability to quickly establish the nature and extent of a threat from an incident such as; a terrorist attack, industrial accident, or hazardous material spill from a train derailment, is crucial to preventing loss of life and property.

This report will be limited to the investigation into the potential applications of UAVs in the detection of radioactive materials.

Radiation Detection Issues

1. Types of Radiation

    a. Alpha radiation:

        Alpha radiation consists of a charged particle with two protons and two neutrons. It is a common decay product from isotopes with a high atomic number, such as; thorium, uranium, and plutonium. Since charged particles lose energy fairly quickly and these are relatively slow, the range of alpha particles in air is only several centimeters. This makes them impractical for use in detection from UAVs.

~~c.~~b. Beta radiation:

Beta radiation consists of an electron emitted from the decay of certain radioactive isotopes. Due to the significantly lower mass, the beta particle travels much faster than an alpha particle and therefore has a longer range. However, the range of a high-energy beta particle is still only several meters in air. This, along with the fairly low probability of emission, precludes the use of beta particle detection as a viable alternative for the detection of radiation using UAVs.

~~d.~~c. Gamma/X-ray radiation:

Gamma rays are released from the decay of virtually all radioactive isotopes, including those isotopes that decay by alpha or beta emission. A gamma ray is a high-energy photon released from the nucleus during decay. X-rays are a similar type of radiation which consists of a photon emitted from the electrons in the atom, not the nucleus. They interact with material in the same manner as gamma rays, thus will be treated the same. Gamma rays have no mass and no charge. Unlike charge particles, the interaction probability of gamma and x-rays in air is very low and therefore they have a longer range. The range of gamma rays in material depends on the gamma energy, the density of material, and the type of material. The range decreases with the increase in the atomic number of the material that the gamma rays are passing through.

It is instructive to look at several isotopes with gamma rays in different energy ranges. For the following isotopes with representative gamma energies, the approximate range in air at which half of the gammas will interact is given below:

Isotope	Gamma Energy	Half-Value Range
^{235}U	186 keV	65 m
^{239}Pu	414 keV	80 m
^{137}Cs	662 keV	110 m

Note that doubling this range would result in ¼ of the gamma rays making it to the detector.

Since gamma rays result from virtually all radioactive decays and they have a relatively long range in air, they are good candidates for detection by equipment placed aboard a UAV.

As the distance from the source to detector increases, the minimum quantity of source material increases. Since gamma rays are emitted in all directions, the number of rays that strike a detector surface (neglecting absorption in intervening material) decreases with the distance squared. Therefore, a detector that is recording 10,000 counts per second (cps) at 10m from a source may have 2,500 cps at 20m, or 100 cps at 100m.

~~c.~~d. Neutrons:
Neutrons are nuclear particles with no charge. They result from nuclear decay (generally spontaneous fission) or certain nuclear reactions (absorption of an alpha particle followed by the release of a neutron). Like gamma rays, neutrons have a very long range in air. However, they are rare, generally emitted in reactors or large quantities of spontaneously fissioning material. The relative lack of neutron sources limits the UAV long-range detection to certain applications, such as reactor accidents like Fukushima, Japan.

For general radiation detection applications using UAVs, gamma ray detectors would be the system of choice. There are many kinds of commercial off-the-shelf detectors with various advantages and disadvantages.

2. Types of Gamma Detectors

a. Plastic Scintillators:

Plastic scintillators are a low-cost detector that is widely used for the detection of radioactive material at ports-of-entry. Other advantages are that these detectors can be made very large and, in combination, can cover large areas such as highways and railways. They are also very robust, and do not require much maintenance. The primary disadvantage is the detectors lack of resolution. As a result, this type of detector is very good for radiation detection, and perhaps location, but ineffective for identification of a radiation source.

There are many commercial manufacturers using plastic scintillators. The systems range from hand-held detectors for site surveys to large portal monitors for vehicle and personnel monitoring.

An example of one of the manufacturers is Rapiscan Systems, which produces several plastic scintillation detectors from handheld to larger portal monitor type detectors. The handheld version, PRM470, has a plastic scintillator with dimensions of 3.5” H x 2.88” W x 1.24” D [8.8 cm H x 7.2 cm W x 3.1 cm D]. The detector can operate from an internal rechargeable battery pack and the detector weighs 2.4 lbs [1.1 kg]. The overall dimensions are 7.75” H x 4.75” W x 3.5” D [19.7 cm H x 12.06 cm W x 8.9 cm D]. The detector is rated for operation from 32 ^{o} to 100^{o}F [0^{o} to 38^{o} C]. A larger version is the Rapiscan PM700. This is a pedestrian monitor with two pillars each housing a 35”H x

10”W x 1.5”D [88.9cm H x 25cm W x 3.8 cm D] plastic scintillator. It has RS-232 serial port and Ethernet communication capability. The overall dimensions are 84” H x 26” W x 8 “ D [214 cm H x 66 cm W x 20 cm D] and weighs 400 lbs [182 kg] per pillar.

While the PM700 is too large and heavy for UAV use, the detector alone with some associated electronics would weigh less than 100 lbs. This would provide the sensitivity for a possible search instrument.

b. Sodium Iodide (NaI) Scintillator:

NaI scintillators are a common spectroscopic detector that has been in use for decades. As such, the technology is well-developed. Another advantage of this detector is that it operates at room temperature, unlike the other common spectroscopic detector high-purity germanium. Crystals can be made rather large 2” x 4” x 18”, but are much more expensive than plastic scintillators. These crystals are commonly used as hand-held search instruments. The advantage of using a NaI detector is that it can be used in search mode or identify mode. Therefore, the same instrument can be used for location and identification.

An example of one of these systems is the FLIR identiFINDER R 400. This is a handheld radionuclide identification device [RIID] which can operate either a 35mm [1.4”]x 51mm [2.0”] NaI scintillation detector with an energy compensated Geiger-Muller [GM] detector for high dose applications. The detector can operate on battery for more than 8-hours. The detector weighs 51.1 oz [1.45 kg]. It has Bluetooth with a range of 32’ 9.7” [10 m]. A larger version is the FLIR identiFINDER R500 which uses a 19mm [0.75”] thick by 102mm [4.02”] diameter NaI(Tl) crystal. This makes it a better detector for longer range applications but weighing more, at 2.9 kg [102.29 oz].

While the hand-held versions may be too small for UAV applications, a larger crystal (such as a 2”x4”x16” crystal) could be utilized that would give significantly better detection efficiency at the same time maintaining the spectroscopic features needed for isotope identification.

c. High-Purity Germanium (HPGe) detectors:

HPGe detectors are a common laboratory detector used for the detection and identification of radioactive isotopes. The excellent resolution of these detectors makes them ideal for gamma spectroscopy. The disadvantages of these systems are that they must be cryogenically cooled and they are significantly more expensive that a NaI detector. The cooling requirement also results in a much heavier instrument. Laboratory systems are generally cooled using liquid nitrogen while field-deployable systems are typically mechanically cooled.

An example of one of these systems is the Ortec/Ametek Micro-Detective. This is a hand-held dose rate/nuclide identifier employing a mechanically cooled HPGE detector. It has a 50mm diameter coaxial type HPGE crystal that is cooled by a Stirling-cycle cryo-cooler. It has wireless capability that can operate up to 5-hours on a single rechargeable Li-ion battery when the detector is cooled. The detector weighs 15.2 lbs [6.6 kg]. The initial cool-down time is 12-hours and can be performed with AC power. When unplugged, the battery power can maintain cooling. The Micro-Detectives overall dimensions are 14.7" L x 5.75" W x 11" H [37.4 cm L x 14.6 cm W x 27.9 cm H]. Power usage during cool down is less than 100 Watts and 5 Amps when charging the battery and 2 Amps when cold with a fully charged battery. The detector performance can be affected by vibration and heat.

The relative small detector size limits the long-range detection and identification capabilities.

d. Lanthanum Bromide ($LaBr_3$) detectors:

LaBr detectors have similar properties as NaI detectors. They both operate at room temperature while the LaBr detector has slightly better energy resolution.

FLIR identiFINDER also makes a LaBr version handheld radionuclide identification device [RIID]. It is a 30mm [1.2"] x 30mm [1.2"] $LaBr_3$ scintillation detector with an energy compensated Geiger-Muller [GM] detector for high dose applications. The detector can operate on battery for more than 8-hours. It has similar weight and Bluetooth range capabilities as the NaI version.

LaBr detectors do not currently have large enough crystals to make them a viable long-range detector.

e. Cadmium Zinc Telluride (CZT) or Cadmium Telluride (CdTe) detectors:

CZT and CdTe detectors are detectors that can operate at room temperature with excellent energy resolution. However, they crystals are much smaller than the other types of detectors and therefore have too small of a detection efficiency to be useful for UAV applications.

Another factor that must be taken into account in the remote detection of radioactive material is the variability in background radiation. Gamma radiation background can vary significantly depending on the geology as well as difference in the signal from man-made structures. For instance, many rock formations are higher in naturally occurring radioactive material (NORM) than soils. As a result, a rock outcropping surrounded by soil could give a positive signal. Certain man-made structures also have a relatively high background signal. Stone or concrete structures may have significantly more NORM than steel or wooden structures.

3. Components of a Detection System

A remote UAV based detections system would have a detector, a transmitter, a method to locate a source, and an algorithm for source identification. One method would transmit the data from the detector in real-time to a command station where the data analysis would be performed. The count rate and GPS coordinates from several locations could be used to find the position of a localized sources using triangulation. Once a source is located, spectroscopic information could be used to determine the source and whether it is a threat.

4. Conclusion

For UAV applications, a detection system needs good efficiency (generally proportional to detector size). If identification of the source is required, a spectroscopic detector would also be necessary. The NaI detector satisfies both criteria. If multiple UAVs were used, then perhaps a plastic scintillator could be utilized for detection and location of a source. Then a NaI system would be used to identify the source.