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Lightweight aerial vehicles for monitoring, assessment and mapping of radiation anomalies

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ABSTRACT

The Fukushima Daiichi nuclear power plant (FDNPP) incident released a significant mass of radioactive material into the atmosphere. An estimated 22% of this material fell out over land following the incident. Immediately following the disaster, there was a severe lack of information not only pertaining to the identity of the radioactive material released, but also its distribution as fallout in the surrounding regions. Indeed, emergency aid groups including the UN did not have sufficient location specific radiation data to accurately assign exclusion and evacuation zones surrounding the plant in the days and weeks following the incident. A newly developed instrument to provide rapid and high spatial resolution assessment of radionuclide contamination in the environment is presented. The device consists of a low cost, lightweight, unmanned aerial platform with a microcontroller and integrated gamma spectrometer, GPS and LIDAR. We demonstrate that with this instrument it is possible to rapidly and remotely detect ground-based radiation anomalies with a high spatial resolution (<1 m). Critically, as the device is remotely operated, the user is removed from any unnecessary or unforeseen exposure to elevated levels of radiation.

1. Introduction

Following the large release of radio-active material at the FDNPP incident (Stohl et al., 2012; Chino et al., 2011; Hirao et al., 2013; Terada et al., 2012; Schoeppner et al., 2013; Morino et al., 2011) only a limited amount of data relating to the quantity and geographical distribution of the released radiation was available to decision makers of evacuation and disaster response (Omoto, 2013; Nuclear Accident Independent Investigation Commission, 2012; Povinec et al., 2013). Static monitoring infrastructure surrounding the site, which had traditionally been used for routine plant monitoring, was compromised following the tsunami, with 23 of the 24 monitoring points rendered inoperable (Omoto, 2013). This resulted in an effective data blackout for radiological information pertaining to the incident, in the hours and days following. It was not until four days following the event, that the first data revealing the extent of radiological contamination in the surrounding area was recorded. This data was produced by a fleet of 15 cars equipped with GM tubes reporting measurements 20 km away from the site (Povinec et al., 2013). Data gathered in this manner presented a potentially significant dose hazard to the operators in return for a spatially limited data set (Nuclear Accident Independent Investigation Commission, 2012). Traditional airborne measurements to identify highly contaminated areas were conducted (Yoshida and Kanda, 2012; Lyons and Colton, 2012) but the results were not made available until 11 days after the incident. These flights used extremely expensive equipment, carrying sensitive and heavy, volume-style radiation detectors, operating at a relatively high altitude (150–300 m) above the surface (Povinec et al., 2013). Resultantly all the recorded data was of low (km scale) spatial resolution and limited to within 30 km of the site (Povinec et al., 2013). The available data, which were obtained through the use of weather prediction models, and assessments of likely released

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radionuclides, were used by advisers to inform the evacuation plan for the surrounding population and the designation of exclusion zones where data readings were not available (Terada et al., 2012; Morino et al., 2011; Povinec et al., 2013). Worryingly, if a similar disaster were to occur today, we still lack the necessary tools to rapidly provide a time resolved, high spatial resolution and accurate plot of radiation released into the environment. Furthermore, traditional radiological assessment techniques would typically subject the operator, whether a driver or pilot, to an unknown and potentially significant radiation dose.

The use of unmanned aerial systems can offer an interesting solution into the detection of radiation in the environment. There have been several previous studies examining aspects of this topic, these include examples which have explored the use of fixed wing aerial vehicles, (Kurvinen et al., 2005; Pllnen et al., 2009) or indoor UAV system (Boudergui et al., 2011), or even very large aircraft (Barnes and Austin, 2009). On these systems a variety of sensor arrays have been tested including air sampling sensors for the detection of airborne radiation particles (Pllnen et al., 2009; Pllnen-b et al., 2009) and scintillating devices (Kurvinen et al., 2005). Fixed wing aircraft (Kurvinen et al., 2005; Pllnen et al., 2009) typically operate at higher altitude (up to 4500 m), and move at a minimum ground speed of 90 km h^{-1}. Here we present a new instrument for detection and assessment of radionuclide contamination in the environment, using small multi-rotor unmanned aerial systems. The instrument incorporates a microcontroller operated, lightweight, low volume, semi-conductor gamma ray spectrometer integrated with a small aerial platform. The instrument securely transmits the location, identity and intensity of radionuclide contamination to a remote operator or base station. Implementing small multi-rotor unmanned aerial systems, and the benefit these systems bring including reduced operation speed and greater manoeuvrability, allows for the device to produce high spatial resolution maps of radiological contamination in the environment.

2. Experimental

The aerial platform consists of a modified multi-rotor (six propeller) aerial vehicle (Hexa XL, Mikrokopter) which records the GPS location of the instrument at a high frequency (10 Hz). At each recorded location a spectrum of the energy of incoming incident radiation is recorded (GR1, Kromek). The height of the device above the surface (±10 mm at <100 m) is simultaneously measured and recorded via the use of LIDAR (AR2500, Acuity). An Arduino mega ADK microcontroller unit is used to combine the data streams (GPS position, LIDAR height, radiation spectra). The data is stored locally on the instrument and concurrently transmitted to the user in real time (500 ms delay) as a 128 bit secured encrypted data stream, to a remote base station which can be up to 7 km from the instrument used to control the device. The payload, consisting of the LIDAR and gamma spectrometer and associated microcontroller, is mounted on a gimbaled stage such that the spectrometer and LIDAR remain directed normal to the surface, regardless of pitch of the aerial platform (see Fig. 1). The system is powered by two 7.4 V lithium polymer batteries giving, currently, a total survey flight time of up-to 12 min, with a maximum aerial speed of approximately 25 m s^{-1}. The presented system has a theoretical ability to survey 18 km of flight path in one flight, however, realistically the survey is typically operated at a slower speed to increase the sensitivity of the instrument. Typically areas of several tens to a hundred meters squared can be surveyed in one continuous flight before the batteries of the system need to be replaced. The batteries take typically 30 min to recharge, requiring 6 batteries in rotation to provide continuous survey coverage. Complementary sensors can be added to the device including thermal and visual cameras. The system can be operated manually, using traditional radio-controls or semi autonomously via programmed GPS way-points. Utilizing simple interface software, these way-points may be pre-selected or transmitted to the instrument in flight. Way-point matrices can generate survey routes that provide detailed geographical coverage of a designated area. The way-points can include automated landing and take-off, such that the device can gather long exposure gamma radiation spectra at a the region of interest. In this case the payload has a relatively small power requirement such that the system may install itself as a static ground-level monitoring point, by landing and reducing flight energy expenditure, for an extended period (weeks). Where landing is not possible, or appropriate, the instrument can hover and autonomously maintain its position over a set location even in severe weather conditions due to its low aerodynamic cross-section. Where possible, typically the instrument is operated at low altitude (<3 m) in order to maximise the radiation sensitivity, reduce the effects of background radiation shine on the instrument and to increase the spatial resolution of the data. Operating at <3 m altitude is only possible depending on the environment the instrument is functioning in. At the lower altitude care must be taken that the instrument does not collide with an obstructing obstacle, which currently is determined by the operator.

3. Materials and methods

The source samples used within this study were specimens collected from the Cornubian batholith, Southwest UK. The batholith consists of six major and several smaller bodies of granite, the larger bodies of granite, from east to west are Dartmoor (600 km^2), Bodmin moor (190 km^2), St Austell (85 km^2), Carnmenellis (130 km^2), Lands End (190 km^2), and the Isles of Scilly (area not defined). The St Austell granitic intrusion, from which the majority of the samples used in the study arise, is a small composite body

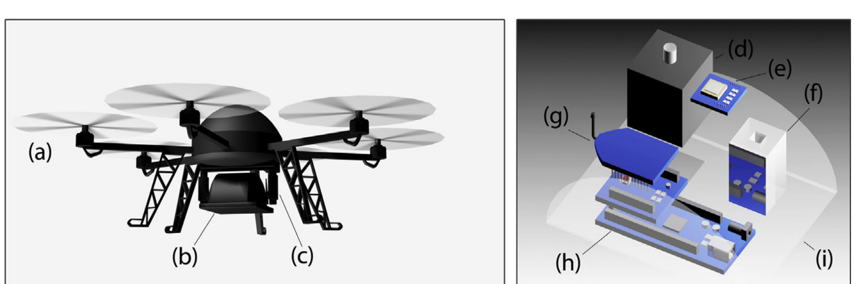

Fig. 1. The radiation detection system, left displays an overview of the system, right an exploded view of payload. a) hexacopter aerial platform, b) integrated payload c)gimbaled stage, d) LIDAR detector e) GPS board f) gamma ray spectrometer g) wireless transmitter h) payload housing.