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Pre-flight experiments for the unmanned aerial monitoring system (UAMS) radioactive detection under its limitations

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ABSTRACT

Over the past few years, drones have become a popular tool for a variety of applications related to nuclear activities, including outdoor and indoor surveys, and dose mapping. Drones have been employed by the industry in terms of improving worker safety, saving time, and reducing costs. In this study, an unmanned aerial monitoring system (UAMS) was designed and fabricated under its limitation to detect radioactive hotspots. The final goal is to map environmental radioactivity and extract radioactive concentration points; therefore, preliminary experiments were performed to reach a robust detection system and also to study effective flight altitudes that UAMS is able to detect anomalies. UAMS consisted of a detection system including a two-inch sodium iodine crystal, a data-acquisition system, and a mini-computer that all were installed under a drone body. One Cs-137 and two Co-60 sources were used for the initial monitoring of UAMS. The results showed that the system is able to detect the sources in the height range of 80 cm to 3 meters.

***Keywords*:** Drone, Aerial monitoring of radioactivity, Detection, Feasibility, Anomalies

I. Introductions

The safety of people and radiologists against radioactive sources in various parts of the nuclear industry has been one of the main human priorities [1]. Hazards such as leakage of radioactive materials, melting of the nuclear reactor core and damage to the site or equipment of radioactive materials holder are serious challenges for humanity, so scientists have been trying to limit the destructive effects of radioactive materials. One of the most effective ways is to employ robots for nuclear activities such as maintenance, manipulation and surveillance which will greatly reduce the risk of direct contact with radioactive materials. Patrols and enviromental insections are some of the tasks that robots can do [2-5]. Radiation environments, such as reactors or even residential environments, require periodic monitoring and inspection after a nuclear incident alarm, Robots can be applied to continuously inspect suspicious areas with minimal human intervention. Robots can be classified by various factors, for instance, based on their control systems, application, or locomotion. According to an environment which robots work, they can be categorized into three traditional groups: aerial, grounded and underwater robots [6]. Advantages of grounded robots are to have a simple structure, carry heavy loads, capable to add different modules and have a longer operation time, so is a suitable

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choice for nuclear applications. But the main challenge is that grounded robots are weak to move on rough surfaces and stairs. In contrast, drones may be used to inspect regions that are inaccessible to grounded robots but drones are limited by their endurance and payload.

In this study, an unmanned aerial monitoring system (UAMS) was designed and fabricated for intelligent navigation and extraction of environmental information under UAMS limitations. The first output of this aerial system is to inspect nuclear sites and detect radioactive materials out of regulatory control. Radioactive sources especially gamma radioisotopes have wide applications in industries such as radiotherapy, industrial and medical imaging, good irradiation and, so on [7]. The radioactive sources may be stolen, lost or moved [8]. The sources with high activity may cause radiation damage to humans or environment neighboring to them. Therefore, one of the most important issues related to protection and safety against radiation is the detection or positioning of radioactive sources.

The next achievement of UAMS is territory surveying, which can be used for mine management and radioactive materials mine exploration [9]. At present, territory surveys are conducted to explore the mines by both aerial and terrestrial methods (monitoring by persons). Because a helicopter (or an airplane) offers low resolution, aerial robots with lower flight altitudes and speeds can identify the location of radioactive materials and their type more accurately. In addition, some areas are impassable for cars or even for individuals [10]. Therefore, monitoring by aerial robots will play an important role in mineral exploration and can fill the gap between monitoring by helicopter and humans and complete their process [11].

Over the past few years, drones have become a popular tool for a variety of applications related to nuclear activities, including outdoor and indoor surveys and dose mapping. Drones have been employed by the industry in terms of improving worker safety, saving time, and reducing costs. One of these involves the use of technology to detect radiation levels during post-accident and repetitive monitoring of the nuclear industry and facilities. Companies around the world are currently developing aerial radioactive monitoring systems. Best drone manufacturers such as the Charlotte UAV and FlyCam are working with manufacturers of radiation monitoring equipment to develop robust systems capable of carrying the required detection system [12]. Some nuclear facilities now use this technology to detect radiation levels. Furthermore, due to the advantages of this method, in some countries, the National Institute for Nuclear, Chemical and Biological Protection has developed a method for aerial measurement of environmental radioactivity using a drone equipped with ionization radiation counters. Companies like NuEM DRONES G use the most advanced technology for aerial surveillance. These systems offer excellent environmental radiation monitoring performance and are designed to explore vast areas, finding orphan radioactive sources and potential contamination. In summary the application fields of UAMS include routine monitoring, nuclear sites, facilities, strategic sites, mapping and monitoring of mines, nuclear accident management, infrastructure protection, emergency response management, terrorist incidents, nuclear accidents, and health physic [13,14]. According to the approach of recent activists in the application of the drone-based radioactivity monitoring, controlling and health physics of nuclear sites, an aerial radiation monitoring system equipped with a radiation detection tool was designed and evaluated. In this research, preliminary experiments were performed by low activity gamma-ray emitting radioactive sources to tune UAMS under common disturbances and show that it can detect radioactive anomalies. Our future goal is to map environmental radioactivity and extract hotspots.

II. Materials and methods

Drone

According to preliminary studies on unmanned aerial robots and similar work in the nuclear field based on autonomous robots, DJI Matrice 600 (M600) is a suitable choice for our application, patrolling the environment and mapping radiation intensity. A front view of the drone used in the present experiment is shown in Figure 1.

Fig. 1. Matrix 600 equipped with a video camera.

Some of its specifications are given in Table 1.

Table 1. Specification of the M600.

Max Takeoff Weight	15.1 kg
Max Angular Velocity	Pitch: 300°/s, Yaw: 150°/s
Max Speed	18 m/s
Max Flight Altitude above Sea Level	2500 m
Max Radio Transmission Distance (unobstructed, free of interference)	5 km

III. Detector Assembly

The detection system consisted of a 2-inch sodium iodide crystal with a high voltage circuit and a single-channel data acquisition system (Figure 2). A mini-computer (Odroid-XU4) and the Ubuntu distribution (Linux) helped us to manage the data acquisition process. The user commands run via the SSH protocol based on an Ethernet connection. The power of the high-voltage system and other electronic parts was provided by the drone batteries and they consumed a current of 500 milliamperes. A diagram of the detection system mounted on the drone was shown in Figure 3.

A holder structure is needed to place the crystal and PMT, which must be attached to UAMS. In addition to the detector, circuits and computer boards also are installed on this structure. The weight of the detector is about 1.8 kg and the holder is robust against vibration and stress during the flight.

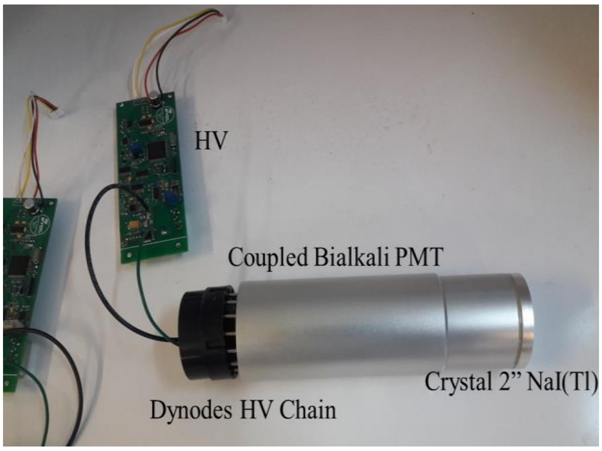

Fig. 2. Prototype mobile sodium iodide detector and electronic board designed for indoor UAV installation.

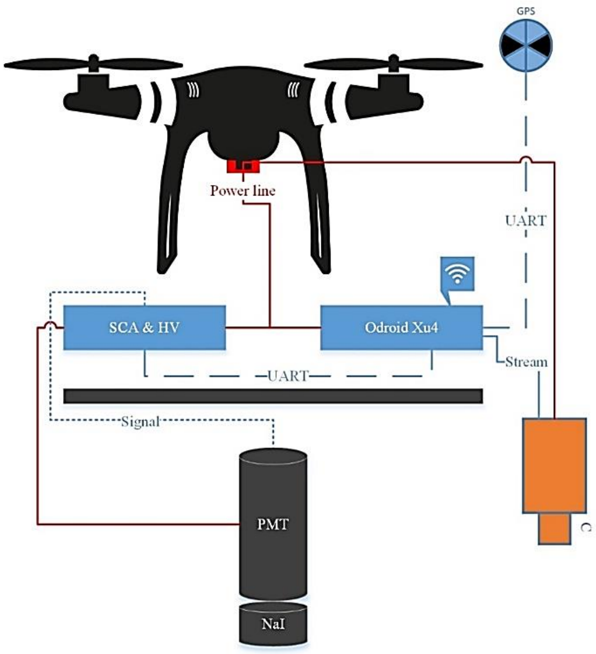

Fig. 3. Diagram of the UAMS components.

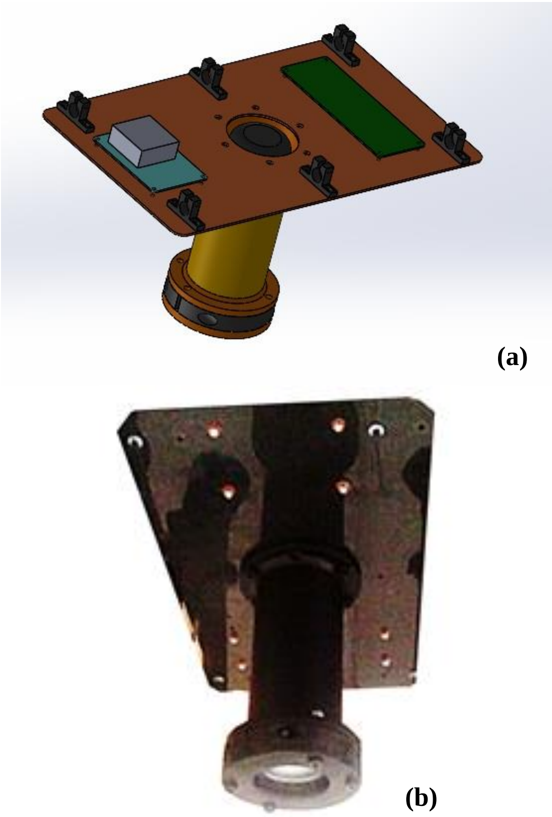

Fig. 4. a. The detector unit layout, **b.** The detector ready to be installed under the UAM.

Fig. 5. The 3D Model of the holder structure assembled on the drone.

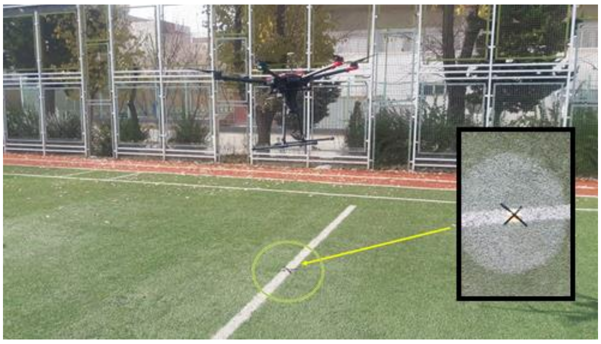

Fig. 6. UAMS is flying above a radioactive source.

In Figure 6, UAMS is flying vertically over one radioactive source. In this experiment, the flying height of UAMS was from 30 cm to 3 meters. By hovering UAMS above each source, the detector was able to record the count at a different height. Two Co-60 with different activities and one Cs-137 source were placed. The characteristics of gamma sources are given in Table 2.

Table 2. The gamma sources in our experiment.

Cs-137	7.32 µCi
Co-60	4.9µCi
Co-60	3.48mCi

The experiments were performed on a sports field. The length and width of the ground were 50 and 25 meters, respectively. The acquisition time for each count is 1 second and the measurement time for each point is about 1 minute. It means that UAMS hovers on each point for 1 minute and the average of 60 gamma counts is considered.

III. Results and discussion

The measurement results for the three sources are shown in Figure 3. The background count in this experiment was about 23 cps. Figure 3 shows the count recorded by the detection system for different heights above the radioactive sources.

Although UAMS had disturbances such as some little side movements and vibrations, but it recorded that gamma counts decreased over the increasing height and with a good approximation the results almost showed the Inverse Square Law. The equations of the fitted diagrams on the counting results recorded in the detector versus flight altitude are given in Table 1.

Although UAMS has presented promising results but it needs to be improved to be reliable and perfect under different conditions and constraints. For instance, rainy weather and strong winds may have adverse effects on UAMS. In addition, multi-rotor drone's endurance is typically between 10 to 45 minutes and for long inspection, the type of this drone may be changed to fixed-wing for instance. In addition, increasing payloads will severely decrease the flight time. To construct a better radioactive mapping in terms of resolution and quality, a heavier detection system may be required which causes the flight time decreases. Trading off between endurance and quality is an important issue that needs to be taken to account in designing of UAMS.

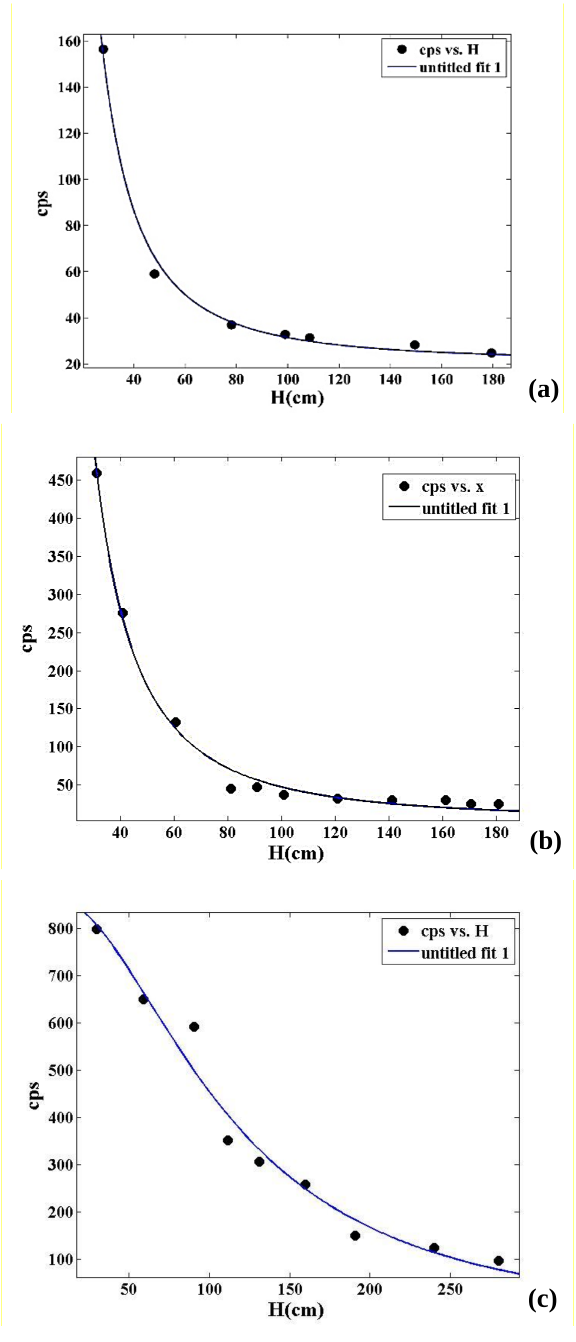

Fig. 7. Count Vs. Height **a.** No1 source (Cs-137, 7.32 µCi), **b.** No.2 source (Co-60, 4.9µCi), **c.** No.3 Source (Co-60, 3.48mCi).

Table 3. Fit parameters for each detected source.

	Fit parameters
Source No.1	General model: f(x) = a*x^-2+b Coefficients (with 95% confidence bounds): a = 1.252e+05 (1.107e+05, 1.398e+05) b = 19.59 (13.24, 25.95) Goodness of fit: SSE: 133.7 R-square: 0.9899 Adjusted R-square: 0.9879 RMSE: 5.171
Source No.2	General model: f(x) = a*(x^-2) +c Coefficients (with 95% confidence bounds): a = 4.402e+05 (4.143e+05, 4.662e+05) c = 3.049 (-6.784, 12.88) Goodness of fit: SSE: 1192 R-square: 0.9939 Adjusted R-square: 0.9933 RMSE: 11.51
Source No.3	General model: f(x) = a/(x^2+b) +c Coefficients (with 95% confidence bounds): a = 1.055e+07 (2.374e+06, 1.873e+07) b = 1.165e+04 (3069, 2.022e+04) c = -33.41 (-185, 118.1) Goodness of fit: SSE: 1.414e+04 R-square: 0.9716 Adjusted R-square: 0.9622 RMSE: 48.54

IV. Conclusions

UAVs have already smashed through rigid traditional obstacles in industries which otherwise seemed impassable by analogous technical innovations. These robots have been about for more than two decades, but their origins age back to World War I while both the U.S. and France attempted to develop the automatic, unmanned flying machines. Aerial camerawork for reporters and directors, disaster management, search and rescue operations by a thermal camera, topographical mapping of remote territory and locations, assessments the building safety, agricultural monitoring, unmanned payload transport, rule enforcement and border control, forecasting of the climate variation are some application examples of UAVs. In the nuclear industry, due to the needs for remote monitoring and control of accidents without the need for human interventions, these devices are very appropriate tools for dosimetry, environmental monitoring and accident management. In this study, pre-flight experiments of UAMS were created to show the capability of this system in future fast mapping and radioactive hotspots detection. For this purpose, a compact detection system including a scintillator detector and data-acquisition system was built and installed under the drone. Three weak gamma radioactive sources were used to evaluate UAMS's ability. The results showed that UAMS can detect sources No. 1 and 2 up to a height of 80 cm and source number 3 to a height of 3 meters under drone disturbances.

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