UAV-Based Radiological Monitoring and Gamma Imaging for CBRN Response

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I. Introduction

In the event of a nuclear or radiological incident, such as the accidental release of ionizing radiation or the spread of radioactive contamination, the first responders require rapid, reliable, and effective procedures for examining and managing the situation. The detection and characterization of radiological hazards in unknown or hazardous environments are key components of CBRN (Chemical, Biological, Radiological, and Nuclear) emergency response. The radiation exposure in this situation should be reduced to minimum according the ALARA principle alongside obtaining useful information about the incident.

UAVs (Unmanned Aerial Vehicles) surpasses the limitation of surveying and accessing extremely hazardous environment. Conventionally, the drone systems are equipped with GM tube and gamma-detectors such as NaI, $LaBr_3$ or CsI detectors in order to gain radiological information of the survey site. However, precise localization and characterization can remain challenging.

The proposed solution overcomes this critical situation by integration a gamma imaging detector system on a UAV drone. The CZT based semiconductor detector offers an advance technology that delivers spectral and spatial informations, enabling quantification and localization of gamma-emitting radionuclide. Due to its compactness, rigidity and operational capability at room-temperature, the detector deemed to be best option for the radiological monitoring missions. The detector have excellent resolution i.e, $< 1\%$ at 662keV and inbuilt temperature compensation.

This study demonstrate the potential of utilizing the advanced imaging capability of a CZT detector for situational awareness. We perform 2 phases of mission in order to carry out radiological mapping and characterize the unknown contamination.

II. Configuration

Fig. 1. Complete UAV-detector assembly (DJI Matrice 400 with H3D M400i payload).

We use DJI Matrice 400 Drone which is capable of automatic flights combined with H3D M400i CZT detector. The drone is equipped with Global Navigation Satellite System (GNSS) for accurate geo-referencing of measurements, micro-controller to process and store data, an altimeter sensor, a camera, and module for data transmission. The gamma imaging detector payload is the fundamental part of this solution which is integrated to the drone with custom-made holder.

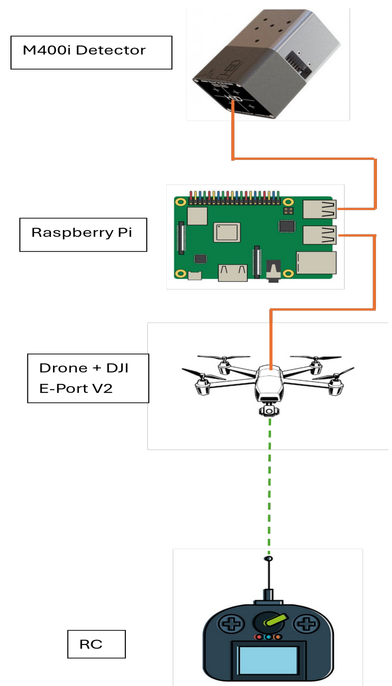

Fig. 2. Hardware integration and data communication architecture of the UAV-based radiological monitoring system.

The data transmission architecture consists of the H3D radiation detector, an onboard Raspberry Pi, and the DJI communication system. The H3D detector acquires radiation measurements and imaging data, which are retrieved and processed by Python-based bridge applications running on the Raspberry Pi. The Raspberry Pi serves as the interface between the detector and the DJI communication module, transmitting the processed data via UART (Universal Asynchronous Receiver-Transmitter). A Payload SDK-based communication program then transfers the data through the drone's wireless communication link to the remote controller and ground-based system. This architecture enables real-time transmission of radiation and imaging data from the airborne platform to the ground station for monitoring and analysis.

III. User Interface

In order to make a user friendly environment, two applications were developed at SYSCADE which form complementary components of the drone-based radiological monitoring system. SyscApp is the real-time measurement and flight-control interface, integrating drone piloting with the radiation detector. It provides live visualization of detector parameters such as dose rate, count rate and identified isotopes/peaks, while enabling the operator to start, stop and restart acquisitions. It also provides a radiation-imaging view to indicate the estimated direction/location of detected radioactive sources, together with access to flight and detector status information. There is also possibility to set dose rate threshold which upon surpassing issues a sound and visual alarm.

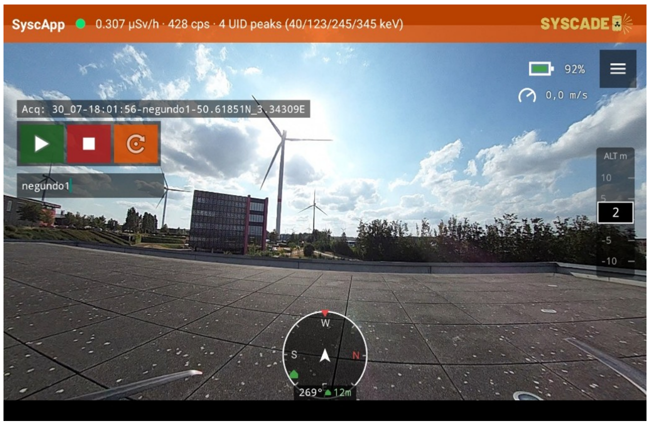

Fig. 3. Pilot view on SysApp.

SysMap, on the other hand, is dedicated to post-flight radiological data management and spatial visualization. It retrieves the measurement records stored during the mission, containing timestamped detector count rate, dose rate, GPS coordinates and flight status, and imports these data into a geo-referenced map. This enables reconstruction of the drone trajectory and visualization of the spatial distribution of radiation levels, supporting subsequent analysis and identification of radiological hotspots.

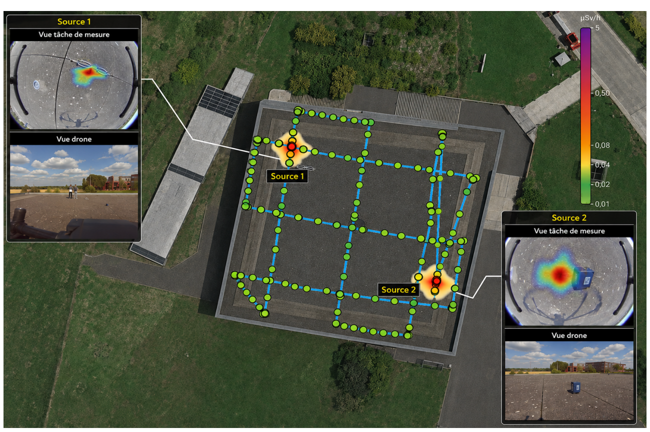

Fig. 4. Dose mapping on SysMap.

IV. Concept of Mission

The radiological monitoring mission is bifurcated in two phases: Surveying & Inspection. The Surveying phase allows large assessment of the environment using the UAV-mounted radiation detector. During this phase, the drone follows a predefined or manually controlled flight path while continuously recording radiation measurements, GPS coordinates, count rate, and dose rate. The objective is to rapidly identify areas showing abnormal or elevated radiation levels and to generate a spatial radiation map of the surveyed area as depicted in the previous section. Upon detection of potential anomaly or hotspot, the mission proceeds to the Inspection phase, where the drone can be positioned closer to the contaminated area or source for more detailed measurement. This phase focuses on characterizing the detected radiation, including the localization of the source, identification of radioactive isotopes through gamma-ray spectrometric analysis. The combination of both phases enables a rapid large-area survey followed by targeted, high-resolution radiological inspection, while reducing the need for personnel to enter potentially hazardous areas.

V. Results

A field trial was conducted to evaluate the system's Surveying and Inspection capabilities with an Eu-152 source of an activity of about 1.8 MBq.

A. Surveying Phase:

The drone executed an automatic flight path covering a large area at an altitude of 3 m and speed of 1 m/s. Over a flight duration of 5 min, 337 measurement points were recorded, as shown in the SysMap trajectory reconstruction (Fig. 4). Dose rates across the survey area ranged from 0.01µSv/h (20 cps) to 0.04 µSv/h (80 cps). One region exhibited an elevated reading of 0.05 µSv/h, flagged as a candidate hotspot for further inspection.

B. Inspection Phase:

Following detection of the anomaly of count rate, the drone was repositioned to ∼100 cm from the position of contamination for detailed analysis. Gamma-ray spectrometric analysis identified 7 peaks, matching Eu-152, as shown in the SysApp radiation view (Fig. 5). The radiation-imaging view precisely estimated the source location.

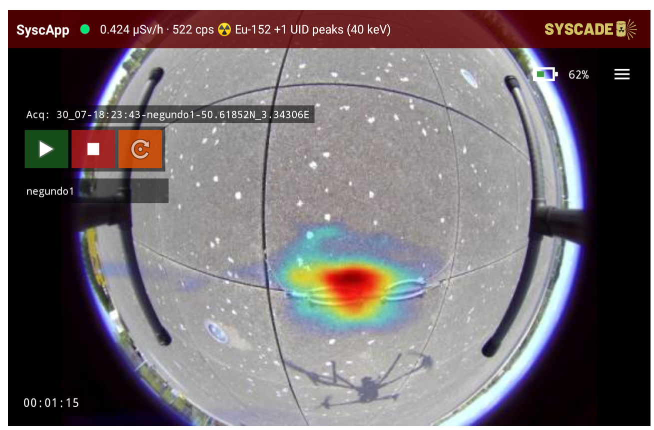

Fig. 5. Radiation View on SysApp.

VI. Future Development

A future development of the UAV-based radiological monitoring system will be the implementation of three-dimensional (3D) radiation dose mapping, extending the current 2D representation of dose measurements along the drone trajectory. In this approach, the radiation measurements acquired by the CZT detector would be combined with the UAV's GNSS position, altitude and flight trajectory, and photogrammetric data, to generate a 3D spatial representation of the radiation field.