DRAGoN: Drone for Radiation detection of Gammas and Neutrons

Davide Brunelli*‡, Felix Pino†§, Cristiano L. Fontana†¶, Lucio Pancheri*‡ and Sandra Moretto†¶

* Department of Industrial Engineering, University of Trento, Via Sommarive 9, 38123 Trento, Italy
†Department of Physics and Astronomy "Galileo Galilei", University of Padova, Via Marzolo, 8, 35131 Padova, Italy
‡INFN - Trento Institute of Fundamental Physics and Applications (TIFPA), Via Sommarive 14, 38123 Trento, Italy
§INFN, Laboratori Nazionali di Legnaro, Viale dell'Università 2, 35020 Legnaro, Italy
¶INFN Sezione Padova, Via Marzolo 8, 35131 Padova, Italy

Abstract—The capability to survey large areas quickly in case of radiation leakages and nuclear disaster is crucial. It saves time, man effort, and protects the operators using remote detection. Thus mapping background radiation of large areas is of primary interest when data can be acquired and analyzed real-time. The DRAGoN project provides a safe and fast method of inspections of nuclear pollution and contamination. It is characterized by its capability of distinguishing between neutrons and gamma radiation types. The system compactness and mobility also permits autonomous measurements and navigation and provides a detailed picture of the radiation levels or contamination surrounding the environment.

I. INTRODUCTION

Nuclear materials are a threat to public health and homeland security in the form of terrorism threats, lost orphan sources, nuclear accidents, or radioactive contamination.

The goal of the Drone for RAdiation detection of Gammas and Neutrons - DRAGoN project is to design, develop, and characterize a mobile system composed of an Unmanned Aerial Vehicle (UAV). The UAV is equipped with a detection system capable of identifying radioactive contamination spread over a few to tens of square meters. Radioactive sources such as neutrons and gamma emitters can be detected on the proposed drone that is designed to accomplish autonomous missions. The designed technology incorporates thermal and fast neutron detectors along with gamma-ray detectors simultaneously.

The measurements are complementary, and their combined efficiency is expected to improve the detection performance. In particular, SNM (Highly Enriched Uranium and Plutonium) are challenging to detect, because they can be easily masked or shielded: therefore both gamma rays and neutrons emitted by SNM have to be detected for increasing the sensitivity against the natural background.

Unmanned aerial vehicles are mainly used in accident scenarios where the doses are too high for a human safety or in areas of difficult access. They are also employed when the static radiation detector network is destroyed, as it happened at the Fukushima Daiichi Nuclear Power Plant in 2011 after the $15m$ high tsunami hit.

There are several designs of UAVs, such as fixed-wing UV or single rotor helicopter-style aircraft. The role of the UAV is to provide fast data acquisition and create an accurate mapping of the zone of interest. Thus, a hexa-copter or a quad-copter gives the highest flexibility in terms of position accuracy, as also demonstrated for other industrial applications such as gas leakage mapping [1], [2]. Some early radiation surveillance solutions with drones are also presented in [3]–[6].

An ideal detector configuration would use a large volume and a very high-density material for the high rate of counting. Such a setting guarantees a high stopping power of the radiation; in other words, a high chance of stopping and detecting radiation. A swarm of UAVs could be very useful for fast static monitoring points within a target zone as demonstrated [7]–[9]. The main challenge is coupling such a weighty detector on a UAV. A potential solution would be to apply a number of small-size detectors and manage the inherent loss of stopping power experienced by these detectors.

There are various detectors used for this application scenario, including Geiger-Muller (GM) tubes, semiconductor detectors, and scintillator detectors. As traversal characteristic, they are mainly focused on detecting and identifying gamma sources and not the neutron radiation.

The DRAGoN solution is characterized by its main capability of distinguishing between neutrons and gamma radiation types. The system compactness and mobility will give a practical instrument to picture of the surrounding environment. The project considers the standards describing the requirements for mobile systems, including the ANSI N42.43. As the system is intended to be used in potentially contaminated areas, experimental tests with relevant gamma and neutron sources are necessary to satisfy the IAEA requirements for safety and security in the field. For instance, one of the requirements is to detect a neutron source in a high gamma background. For this reason, the capability to distinguish between the two sources
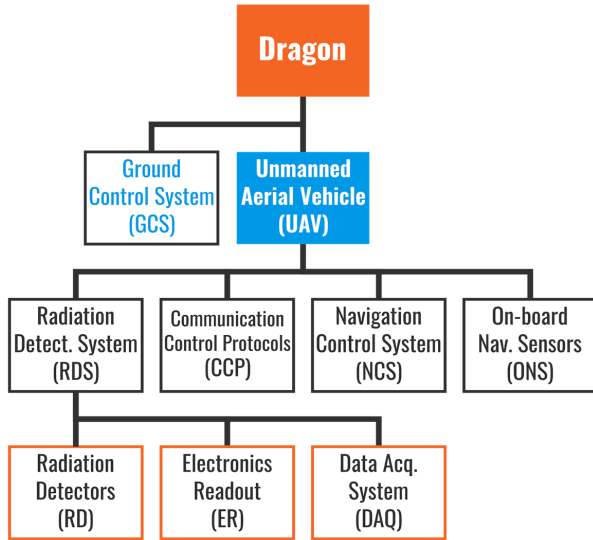
Fig. 1. Tests with the assembled UAV

Fig. 2. The DRAGoN project constituents scheme

is a significant added value.

II. DRAGoN PROTOTYPE DESCRIPTION

An important aspect of DRAGoN project is finding miniaturized solutions both for the detectors and the electronics. The DRAGoN drone is presented in Figure 2. The Unmanned Aerial Vehicle has been realized as depicted in Figure 1 and, at a functional level, provides both an autonomous real-time path planning, and a flight controller to allow manually pilot of the drone, guaranteeing safety with redundant input; and a telemetry communication using a dedicated 2.4 GHz radio link.

The Radiation Detection System (RDS) uses two detection solutions:

– Radioactivity counter monitor: plastic scintillator EJ276 (Excellent physical hardness, Long-term stability of scintillation and optical characteristics).
– Radionuclide identification system: Gamma spectroscopic scintillator with neutron detection capability (CLLB).

The two solutions are designed to be interchangeable with the same electronics readout, thanks to a suitable mechanical design, in order to adapt the system to the requirements of a variety of threats in nuclear security. The first solution is employed as a radioactivity counter, whereas the second solution is used for a second-line identification system. Moreover, the second solution can be used as a first line inspection system for very high dose environments, like in catastrophic events involving high quantities of neutron emitting materials.

For both the solutions, a standard Photomultiplier Tube (PMT) is used to detect the scintillation light signal. An alternative readout channel, based on large-area Silicon Photomultipliers, is also developed to reduce the overall weight, size, and power consumption of the detection system.

A 125 MHz digitizer is then mounted on the UAV to complete real-time wireless measurement. The reduction of the sampling rate reduces energy consumption, which can be partially compensated by increasing the number of bits of resolution up to 14 bit. The digitizer is controlled by an FPGA to achieve the necessary speed for the detection and signal processing, and improve the efficiency of the reader. This combination allows to install an embedded operating system (e.g. Linux) that can run the necessary software for the Data Acquisition (DAQ). The integrated FPGA executes the data preprocessing efficiently and serves it directly to the CPU. This hybrid solution simplifies the development effort, as only the high-performance data processing is delegated to the FPGA. The total processing time for a radiation detection event shall be no more than 10 μs, to allow the acquisition of about 10^3 event/s .

A. UAV architecture

The selection of the UAV frame is important as it determines the stability in wind conditions and maximum payload lift of the vehicle, particularly with the used Radiation Detection System, which weights >2 Kg. For the sake of completeness, a 6-propellers frame was used with 750 KV brush-less motors and 50 A motor controller. The flight controller used is a Pixhawk, and a quadcore processor-based companion board was used for the measurements. Moreover, the board manages (i) the fly parameters, acting as a bridge between drone and Ground Control Station (GCS) using a WiFi link and (ii) opportunely interfaces the sensors, streaming the data to the GCS. The nominal cruise speed of this type of applications is relatively low compared to the maximum speed achievable the UAV, and it ranges between 10-40 Km/h. A Linux-based Operating System capable of managing multiple processes (e.g. flight control) is used to interface to the Radiation Detection System (RDS).

III. EXPERIMENTAL RESULTS

The experimental results of the radiation detection system concern overall capabilities. As first, the radioactivity counter,
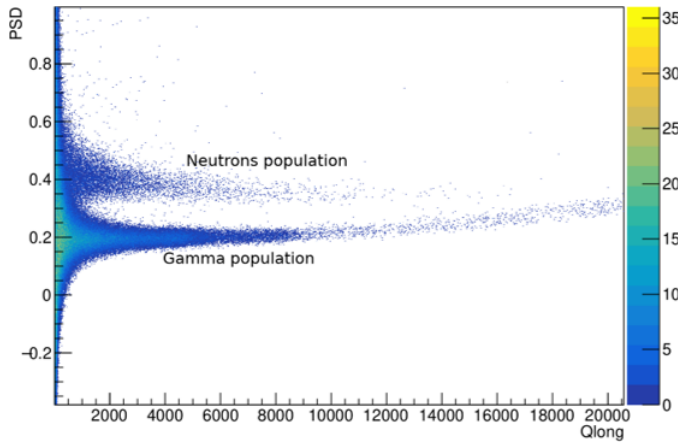
Fig. 3. Pulse shape discrimination plot in which the gamma-rays and neutrons populations are easily distinguished. Acquisition of a ^{252}Cf source with a EJ-276 plastic scintillator and a Digilent Analog Discovery 2 USB oscilloscope.
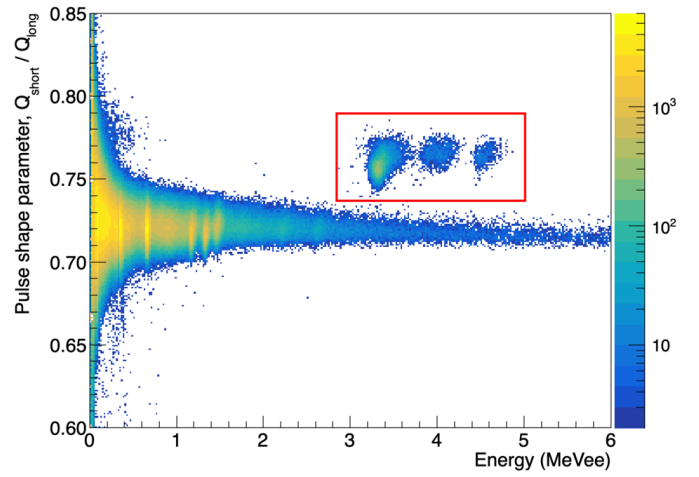

Fig. 4. 2D plot, PSP parameter versus energy for the CLLB, with the clear identification between gamma and neutron/alpha events.

based on a large size (70 mm dia. × 130 mm thick.) plastic scintillator EJ-276 (from Eljen Technology, Texas), has been tested. This new plastic scintillator discriminates between gamma and fast neutrons, with a Pulse Shape Discrimination (PSD) [10] capability similar to the best liquid scintillators. Fig. 3 shows a typical 2D plot (PSD parameter vs energy) corresponding to a measurement of a ^{252}Cf source. The neutron yield of the radioactive source was about $5.2 \times 10^4 \pm 20\%$ at the time of the experiments. Two clusters of events are observed, one for each kind of particle. Fast neutron and gamma ray count rates can be derived by selecting the events belonging to each cluster. As a first approximation, events with PSD > 0.3 are tagged as fast neutrons, otherwise, they are classified as gamma rays. Energy threshold (Qlong) could be also set to avoid the misclassification at very low energies. A compact digitizer with a sampling rate of 100 MHz was used in the test. The Figure of Merit (FoM) measured in this configuration is 1.25, at a threshold of 250 keVee. The FoM is a parameter that describes the goodness of the gamma/neutron discrimination at a specified threshold.

The second solution, used for the second-line identification system, is based on a 2" × 2" CLLB scintillator. It has the capability of measuring gamma rays (with good energy resolution to perform spectroscopy analysis) and thermal neutrons (via neutron capture reaction on ^{6}Li). The scintillator was coupled to a R6231 Hamamatsu photomultiplier. The PMT signals were acquired by a CAEN DT5725 fast digitizer (250 MSamples/s, 14 bit ADC resolution). The PMT bias voltage (+1150 V) was applied using a CAEN V6533 VME HV Power Supply Module.

The laboratory characterization was focused on the source identification capability, by performing gamma spectroscopy, in an intense thermal neutron flux background. The radioactive
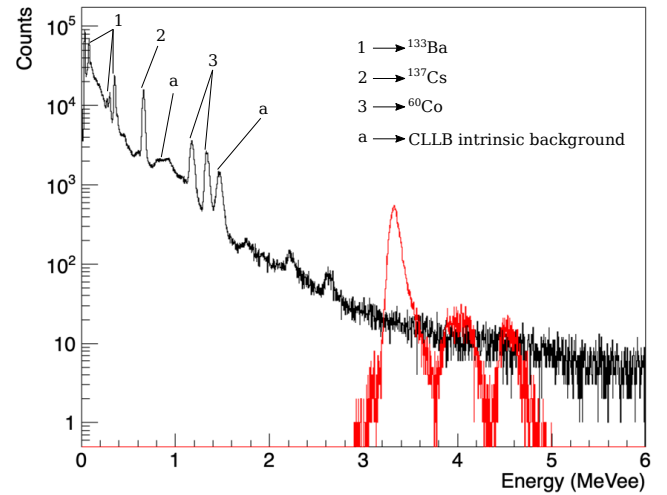

Fig. 5. The multiple gamma spectrum using the CLLB with the PSP filter to select only gamma events. In red the thermal neutron peak and alpha background of the CLLB.

sources used were ^{133}Ba, ^{137}Cs, ^{60}Co, and ^{252}Cf (the latter was shielded by 6cm of polyethylene). Fig. 4 shows the CLLB 2D plot, Pulse Shape Parameter (PSP) versus energy [11], demonstrating the good discrimination between gamma and neutron/alpha events (red box).

Fig. 5 shows the CLLB gamma spectrum with a gamma PSP filter. By using a simple deconvolution of the spectrum, the identification of the gamma sources (^{133}Ba, ^{137}Cs, ^{60}Co) can be achieved. The peaks labeled a are the CLLB intrinsic background peaks. Moreover, it is possible to recognize the presence of the thermal neutron source by analyzing the PSP neutron-alpha separation (see Fig. 4 red curve, first left peak).

IV. Conclusion

In this paper, we presented DRAGoN, a drone for radiation detection of gammas and neutrons. DRAGoN incorporates thermal and fast neutron detectors along with gamma ray detectors simultaneously. This novelty is particularly important for the detection and identification of SNM. DRAGoN uses two detection solutions based on a Radioactivity counter monitor and a Radionuclide identification system, both designed to be interchangeable with the same electronics readout. Experimental results demonstrate the feasibility and performance of the presented approach. The drone executes a first quick scan of a large area to localize neutron and gamma sources, and a second more detailed analysis for gamma sources identification.

References

[1] M. Rossi and D. Brunelli, "Autonomous gas detection and mapping with unmanned aerial vehicles," *IEEE Transactions on Instrumentation and Measurement*, vol. 65, no. 4, pp. 765–775, 2016.

[2] M. Rossi, D. Brunelli, A. Adami, L. Lorenzelli, F. Menna, and F. Remondino, "Gas-drone: Portable gas sensing system on UAVs for gas leakage localization," in *SENSORS, 2014 IEEE*, 2014, pp. 1431–1434.

[3] K. Kurvinen, P. Smolander, R. Pöllänen, S. Kuukankorpi, M. Kettunen, and J. Lyytinen, "Design of a radiation surveillance unit for an unmanned aerial vehicle," *Journal of Environmental Radioactivity*, vol. 81, no. 1, pp. 1–10, Jan. 2005.

[4] P. Martin, O. Payton, J. Fardoulis, D. Richards, and T. Scott, "The use of unmanned aerial systems for the mapping of legacy uranium mines," *Journal of Environmental Radioactivity*, vol. 143, pp. 135–140, May 2015.

[5] P. Gong, X.-B. Tang, X. Huang, P. Wang, L.-S. Wen, X.-X. Zhu, and C. Zhou, "Locating lost radioactive sources using a UAV radiation monitoring system," *Applied Radiation and Isotopes*, vol. 150, pp. 1–13, Aug. 2019.

[6] J. Han, Y. Xu, L. Di, and Y. Chen, "Low-cost Multi-UAV Technologies for Contour Mapping of Nuclear Radiation Field," *Journal of Intelligent & Robotic Systems*, vol. 70, no. 1-4, pp. 401–410, Apr. 2013.

[7] V. Gallego, M. Rossi, and D. Brunelli, "Unmanned aerial gas leakage localization and mapping using microdrones," in *2015 IEEE Sensors Applications Symposium (SAS)*, 2015, pp. 1–6.

[8] P. Tosato, D. Facinelli, M. Prada, L. Gemma, M. Rossi, and D. Brunelli, "An autonomous swarm of drones for industrial gas sensing applications," in *2019 IEEE 20th International Symposium on "A World of Wireless, Mobile and Multimedia Networks" (WoWMoM)*, 2019, pp. 1–6.

[9] D. Facinelli, M. Larcher, D. Brunelli, and D. Fontanelli, "Cooperative UAVs gas monitoring using distributed consensus," in *2019 IEEE 43rd Annual Computer Software and Applications Conference (COMPSAC)*, vol. 1, 2019, pp. 463–468.

[10] T. Marchi, F. Pino, C. L. Fontana, A. Quaranta, E. Zanazzi, M. Vesco, M. Cinausero, N. Daldosso, V. Paterlini, F. Gramegna, S. Moretto, G. Collazuol, M. Degerlier, D. Fabris, and S. M. Carturan, "Optical properties and pulse shape discrimination in siloxane-based scintillation detectors," *Scientific Reports*, vol. 9, no. 1, pp. 1–13, Jun. 2019.

[11] R. S. Woolf, B. F. Phlips, and E. A. Wulf, "Characterization of the internal background for thermal and fast neutron detection with CLLB," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 838, pp. 147–153, Dec. 2016.