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DRAGoN: Drone for RAdiation detection of Gammas and Neutrons

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Summary. — The Dragon project's goal is to design, develop and characterize a mobile system composed of an Unmanned Aerial Vehicle, with a Radiation Detection System capable of identifying radioactive contamination spread over an area of a few to tens of square meters. The capability to quickly survey large areas in case of radiation leakages and nuclear disaster is crucial. It saves time, money and protects personnel using remote detection. It represents an innovative solution for the detection and identification of radioactive materials in a specific area. The proposed technology incorporates thermal and fast neutron detectors along with gamma ray detectors. These measurements are complementary: their combined power is expected to improve the system performances. 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. An overview of the DRAGoN status will be presented, starting from the detection system, the electronic and the first tests.

1. – Introduction

The goal of the Dragon project is to develop a mobile system composed of an Unmanned Aerial Vehicle (UAV), equipped with a detection system able to identify unknown radioactive sources spread over an area of a few to tens of square meters, like gamma emitters and special nuclear materials (SNM). Moreover, it can be easily brought to the site rather than bringing the suspicious vector to the screening device. Being mounted on a UAV, the detection system and electronics have been defined by size, weight and power constraints. The proposed prototype is an all-in-one detection solution: thermal and fast neutron detectors along with gamma ray detection. These measurements are complementary, their combined power improves the system performances. Unmanned ground and aerial vehicles (UGV and UAV respectively) are mainly used in large and

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unknown scenarios, in accident cases where the doses are too high for a manned survey or in areas of difficult access [1]. An ideal detector configuration would employ a very high density material for a high counting rate and a large volume. Such configuration guarantees a high stopping power of the radiation, in other words a high chance of stopping and detecting radiation. While such a detector would not be suitable for deployment on a UAV due to its weight, a swarm of UAVs could be implemented to establish static monitoring points within a target zone. Using a number of these systems equipped with the traditional smaller volume detectors in a single target survey is a potential solution for the inherent loss of stopping power experienced by these detectors. fA traversal characteristic, to the more common used monitoring systems, is that they are mainly focused on detecting and identifying gamma sources and not neutron radiation [2, 3]. The Dragon solution is characterized for its main capability of distinguishing between neutrons and gamma radiation types. The system compactness and mobility gives a practical instrument to picture the surrounding environment.

2. – The Dragon project

The Dragon project's goal is to prepare a first prototype of a mobile system composed of an Unmanned Aerial Vehicle (UAV), with a Radiation Detection System (RDS) capable of identifying radioactive contamination spread over an area of a few to tens of square meters. The Dragon prototype detect and discriminate simultaneously gamma and neutron radiations. The proposed Dragon project structure is presented in fig. 1.

In this paper, an overview of the main components will be done, in particular on

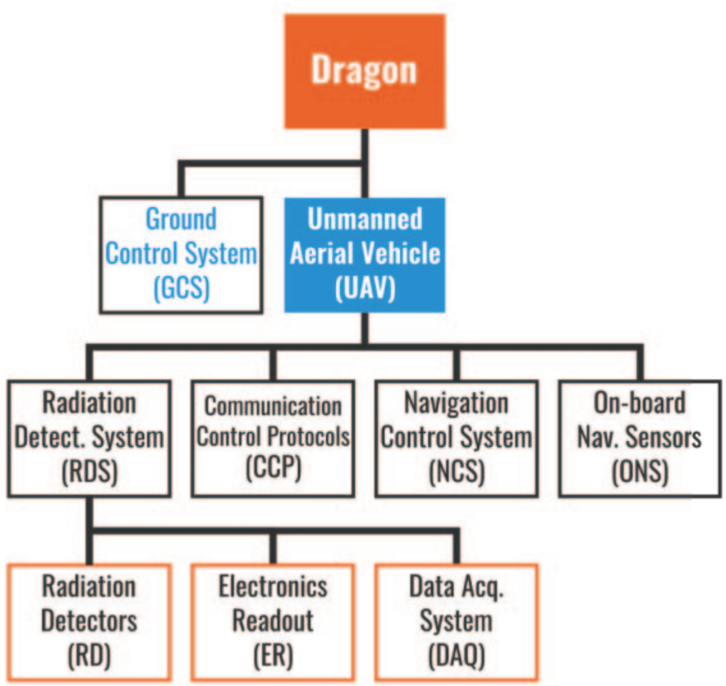


Fig. 1.: Dragon project structure.

the Dragon UAV and on the Radiation Detection System (RDS). An example of the the Ground control system (GCS) will be shown.

3. – The Dragon UAV

The Dragon UAV solution is based on DJI Matrice 600 Pro prototype, with 1133 mm Wheelbase and maximum payload and takeoff of maximum 5 kg. The UAV hexacopter has been assembled and calibrated extensively. The flight time was tested to be up to 38 min. The software for remote control was based on Raspberry4 SBC, and it was used to control the Dragon acquisition system and to keep wireless contact to the ground station, via a 2.4 GHz downlink to based station. The fully integrated software is flexible and scalable enough to adapt to different requirements, like a swarm of UAV.

The environmental requirements for the UAV follow:

1) Flight with wind speed up to 10 m/s.

2) Flight in areas with < 50 °C air temperature;

3) Flight in clear sky weather conditions.

At functional level the system will provide the functionalities as follows:

1) UAV navigation:

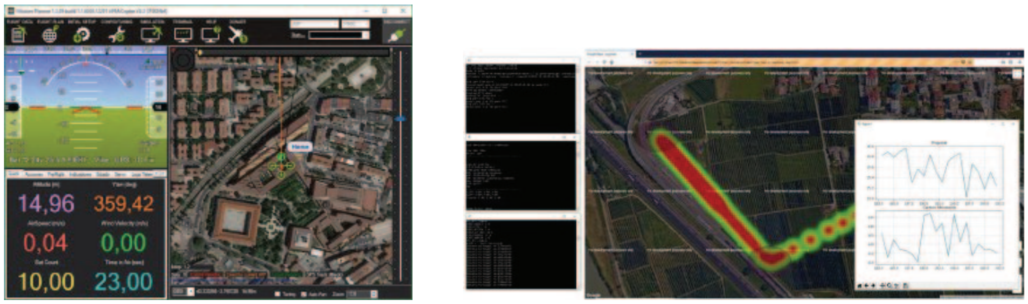
- Flight Control: this function allows to manually pilot a UAV, guaranteeing safety with redundant input
- Communication: this function allows the UAV to communicate on one side, with the ground system using a dedicated 2.4 GHz radio link and, on the other, with the remote controller using a dedicated 2.4 GHz link (this must be available for safety compliance).

2) UAV path planning:

- Data Logging: this function locally logs all information coming from the UAV including flight parameters and radiation detection readings;
- Task planning: this function is responsible for the planning and control of the mission to be accomplished by the UAV. The mission is based on the detection policy and the specific sensor system mounted on the drone.
  – Mission planning occurs before take-off based on user input;
  – Mission control occurs in real-time sending instruction to the UAV;
  – In normal operation the Fast Area Mapping is active;
  – Once the area of interest has been defined by the user the UAV reduced the movements speed for a smoother map of the area.
  – Data Visualization: this function is responsible for the graphical representation of the UAV flight parameter and radiation data for the operator.

3˙1. *The Ground control system (GCS).* – The Ground control system checks the UAV position on a map, visualizing at a glance the flight state and generating a safe path for the UAV. An example of the visualization is presented in fig. 2.

The Unmanned Aerial Vehicle provides both an autonomous real-time path planning, and a flight controller to allow manually pilot of the drone, guaranteeing safety with redundant input.



(a) (b)

Fig. 2.: An example of the ground control system visualization. Panel (a) shows the main visualization of the GCS with the map overview and some parameters of the UAV sensors. Panel (b) represents the results of the detection system with the neutron and gamma results.

4. – The Dragon radiation detection system

The radiation detection system (RDS) employs two detection solutions. The first one is a radioactivity counter, based on a plastic scintillator ($EJ276$), [4]. The second one is a Radionuclide identification system, based on an inorganic scintillator, CLLB [5], a gamma spectroscopic scintillator with neutron detection capability The first solution will be employed as a radioactivity counter, whereas the second solution will be 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.

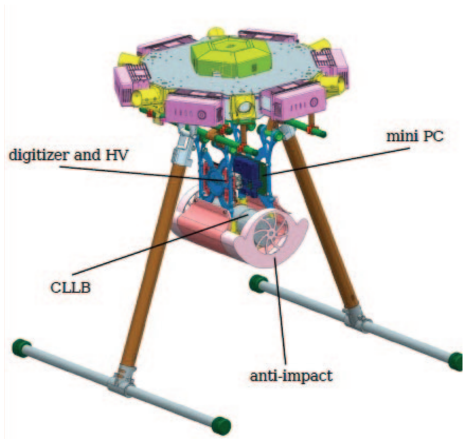
The two solutions will be designed to be interchangeable with the same electronics readout, thanks to a suitable mechanical design, in order to adapt the system to the requirements of a variety of threats in nuclear security. In the picture, fig. 3, a 3d rendering of the mechanical solution adopted below the drone is presented: the mechanical electronic and computer dedicated space (in blue) and a detector safety holder which will be the unique part to be dismounted for the two solutions.

4˙1. *Counter*. – The radioactivity counter is based on a plastic scintillator EJ-276: cylindric shape, diameter of 120 mm × 70 mm. The readout is based on a photomultiplier (PMT) model Hamamatsu H6559 The scintillator is coupled to a 2″ dia. PMT (R6231) Hamamatsu photomultiplier together with a voltage divider (AS20). STEMLAB 125-14 (125Ms/s, 14-bit ADC resolution, power consumption 2 A 5V) [6]. The Red Pitaya is a portable light digitizer with two input channels, installed in the DRAGON project, due to its light weight and low power consumption. All the tests have been done acquiring the PMT signals by two different digitizers: a CAEN DT5725 fast digitizer (250MSamples/s, 14-bit ADC resolution and Digital Constant Fraction Discriminator, DCFD, embedded in the firmware for precise timing measurements [7]) as reference and the Red Pitaya.

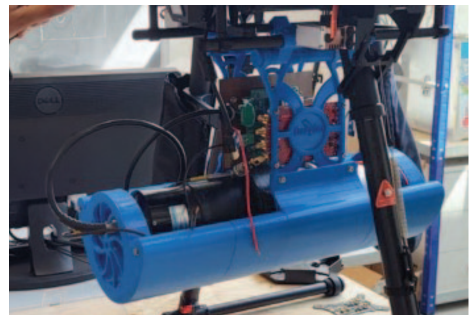
The main important results can be found in [8], here we present only the more important ones for the present scenario:

1) Gamma efficiency as a function of the angle: Angles do not affect the efficiency, $\epsilon\_abs \approx 0.2$

2) the Figure of Merit (FoM) $FoM(n_{th} - \gamma) = 1.42$



(a)



(b)

Fig. 3.: Panel (a) shows the 3D rendering of the detector system holder. Panel (b) presents the Dragon final prototype for the detector system holder.

Moreover, up to 3 kHz (about 3 time more the natural radioactivity), the rate of lost events is only about 15% and there is no a significant increase in the neutron identified region.

4·2. *Radionuclide identification system.* – The Radionuclide identification system is based on a $2'' \times 2''$ cylindrical CLLB scintillation detector, with density equals to 4.2 g/cm^3, its light output is 40000 ph/MeV and with wavelength of maximum emission equals to 420 nm and decay time, according to the manufacturer, 180 ns (50% for neutron and 61% for gamma) and 1080 ns (50% for neutron and 39% for gamma) The CLLB scintillator is coupled to a $2''$ diameter PMT (Hamamatsu R6231). A complete characterization of the detectors was performed [9]. In particular, the discrimination capabilities of the detector $(n_{th} - \gamma)$ using the ^{252}Cf source and a 6 cm of polyethylene used as moderator is $FoM(n_{th} - \gamma) = 2.05$. The neutron detection capability under a high γ counting rate, observing the neutron counting rate while the γ rate is increased, using the ^{252}Cf and a ^{60}Co source is ($\sim$ 5 mCi). An important capability of the CLLB detector is its sensitivity to fast neutrons. We tested it at the CN facility (LNL). In the 2D-Pulse Shape Parameter (PSP) plot it is visible another cluster of events, besides thermal and gamma radiation, see yellow box in fig. 4. Detection of fast neutron occurs through elastic scattering of the neutrons with the Li nuclei.

The integration test of the full prototype has been performed with the following goals:

1) Communication test

2) Electronics integration test

3) Mechanics test

In the communication test we checked, in particular, the Radiation Detection System Red Pitaya - Raspberry UAV communication performances. The visualization of the Neutron and Gamma rates and the UAV GPS information. The electronic test was related to the integration of the UAV battery, Red Pitaya digitizer and the HV module.

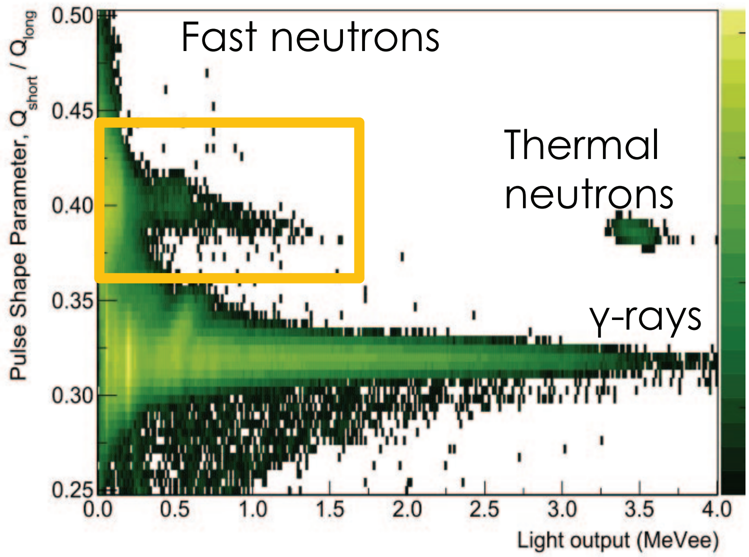


Fig. 4.: 2D-PSP parameter plot of CLLB.The yellow box represents the fast neutron region.

(a)

(b)

Fig. 5.: The final prototype integration test. In (a) the side view and in (b) the front view of the Dragon prototype.

The last test was the whole integration of the final mechanics for detection system to final UAV. In fig. 5 the prototype fully equipped is presented, (a) side view and (b) front view of DRAGON UAV.

5. – Conclusion

At the current status of the investigation, we conclude the DRAGON project represents a new tool with comprehensive inspection (gamma and neutron detection capabilities) on a single UAV. Moreover, the system will be studied to fit the challenges of a variety of threats in nuclear security. Possible employment scenarios in high gamma and neutron doses environments. The DRAGON project will conduct further tests related to the real flight conditions, like flight and speed requirements in terms of minimum detectable emission rate. These tests are still on going.

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