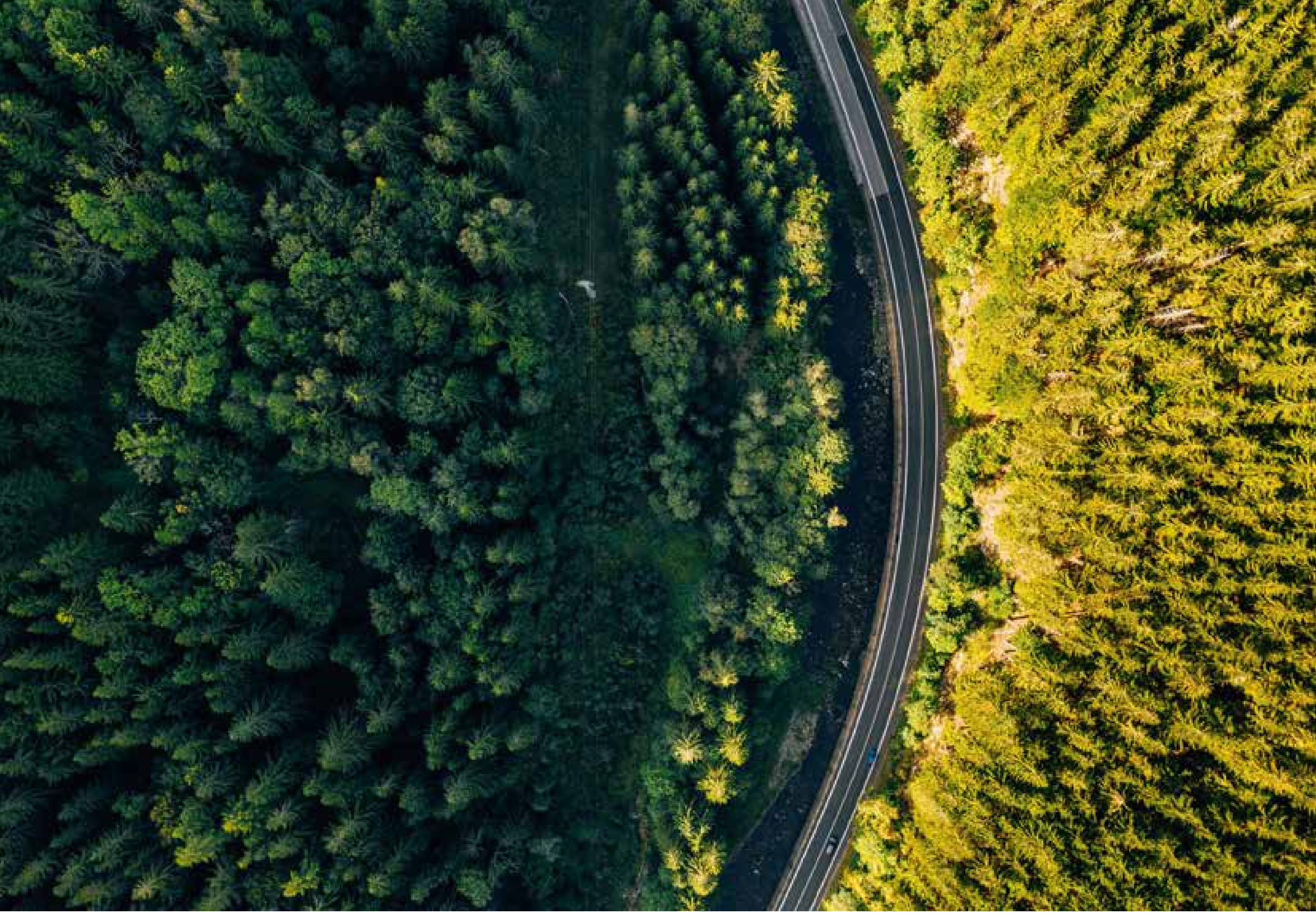

Real-time route optimization of a drone

An Artificial Intelligence application to automatically detect people beneath the drone and to optimally reconfigure its mission

By Giovanna Castellano[1], Ciro Castiello[1], Carmela Agnese De Donno[3], Arturo De Marinis[1], Angelo Emanuele Fiorilla[2], Michele Iacobellis[3], Felice Iavernaro[1], Francesca Mazzia[1], Corrado Mencar[1], Rosa Maria Mininni[1], Andrea Palumbo[3], Gino Perna[4], Gennaro Vessio[1]
1. Università degli Studi di Bari Aldo Moro - 2. Vitrociset S.p.A. - 3. Planetek Italia S.r.l. - 4. EnginSoft S.p.A.

Current regulations place various constraints on the flight of autonomous drones, e.g. prohibiting them from flying over concentrations of people. We report an implementable workflow for drones that automatically detects people and/or crowds in the underlying territory and consequently optimizes the flight plan to minimize the risk of impact with a crowd during an emergency landing.

The greater availability of sensors and devices suitable for drone payloads, which can capture increasingly precise and targeted information and transform it into digital data for processing, has exponentially increased the number of potential applications for drones in both the military and civilian sectors. Among the potential civilian applications are: environmental monitoring, monitoring of areas affected by natural disasters such as earthquakes, floods,

Fig.1 - The route optimization workflow

and fires; search and rescue operations in emergency situations; remote sensing to create maps identifying areas of interest, etc. Drones are mobile devices that can reach relatively high speeds by moving independently through the air, thus offering the advantage of movement that is unrestricted by the characteristics of a given territory or route. To enable automatic piloting, these devices must be equipped with appropriate sensors that acquire and communicate data to special processing units which run specific software to process the data in order to make piloting decisions to achieve a high-level goal (mission).

The drones' missions are subject to restrictions imposed by European Union Aviation Safety Agency (EASA) as well as to environmental and territorial limitations. These are particularly important because of the increasing use of drones in Urban Air Mobility tasks, which require strict safety constraints for their operation. In particular, the European Commission Implementing Regulation (EU) 2019/947 "on the rules and procedures for the operation of unmanned aircraft" prescribes, for the Open Category of drone operations, that "the remote pilot [shall] ensure that the unmanned aircraft is kept at a safe distance from people and that it is not flown over assemblies of people".

Nevertheless, unforeseeable problems, such as sudden adverse weather conditions, GPS failure or degradation, loss of data link with the remote pilot, etc. may occur which could still cause the drone to fly over assemblies of people. The goal of the research is to develop a solution to enable drones to:

1. automatically detect people and/or crowds in the territory beneath them;

and consequently to

2. optimally redefine the flight plan (mission) to avoid the people.

These operations are necessary to adapt the flight path in real time to bring the drone into safe areas so that the risk of impact with people during an emergency landing is minimized. This challenge led to the development of a research project being conducted jointly in partnership between the Italian universities[1] and the top-level industrial partners[2] in the RPASInAir project[3], which is co-funded by the European Structural and Investment Fund (ESIF) and the Italian "Programma Operativo Nazionale (PON) Ricerca e Innovazione 2014-2020" fund. This research project is affiliated to the growing research infrastructure of the "Taranto Grottaglie Airport Test Bed"(IATA: TAR; ICAO: LIBG)[4].

The proposed workflow

Analysis of the problem led to the definition of a workflow for path optimization that includes the following steps:

1. Planning the initial drone route based on the goals and constraints of the mission;

Fig. 2 - The prototype drone is an eight-copter unmanned aerial vehicle (UAV) equipped with a gimballed camera and on-board computing capabilities

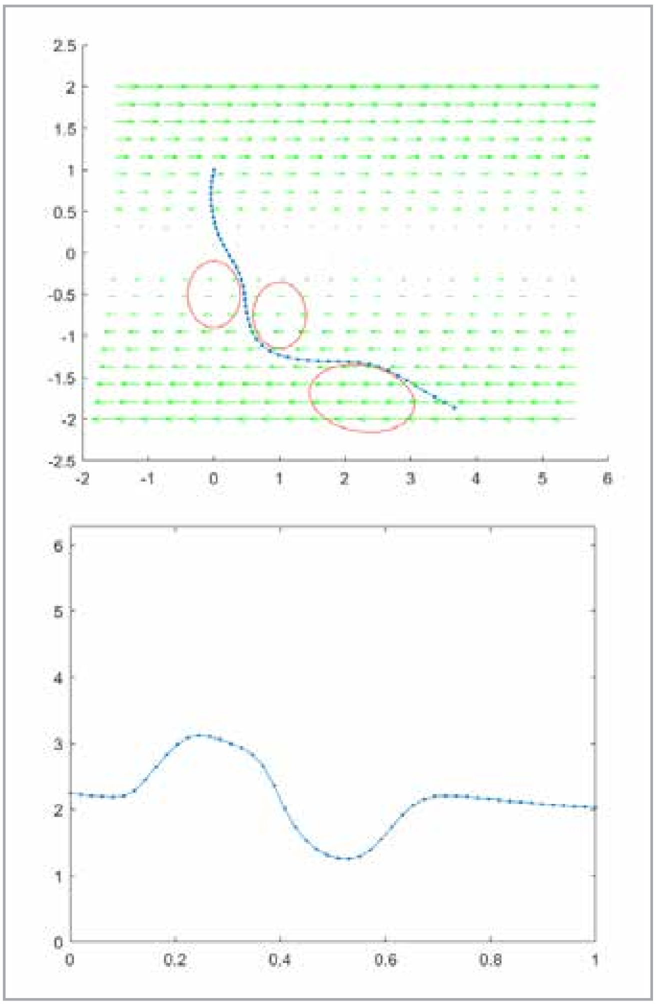

Fig 3 - a) (Left) Optimal trajectory in a windy area with three obstacles . b) (Right) Yaw angle as a function of time to achieve the optimal trajectory .

2. Continuous acquisition of images and telemetry by the drone's sensors;
3. The generation of bounding boxes to detect individuals of terrain to be avoided;
4. The use of geo-referenced images, bounding boxes, and telemetry to provide images and telemetry with spatial and temporal metadata;
5. Re-routing of the flight based on recognized ground patterns to be avoided.

The prototype drone to be used for the final tests is a multi-rotor aircraft equipped with eight engines/propellers, with a load capacity of not less than 1.5 kg, and a variable range depending on the total weight, but in any case not less than 15 minutes. Intermediate tests will take place in a simulated environment.

The workflow is executed by a network of software modules, which are interconnected through efficient inter-process communication technologies. The Manager module allows the on-board high-level algorithms and applications to interface with the ground control station (GCS). The software enables different flight and/or mission functions to be controlled, as well as receiving periodic telemetry messages from the ground control station. The Manager module also receives an initial flight plan as a list of waypoints from the GCS.
This flight plan is the result of an optimization process that takes into account the presence of interdicted areas, fixed obstacles, etc. It is realized using mathematical methods that follow the "optimize then discretize" paradigm.

These are based on the variational calculus and transform the problem of optimal control into a Hamiltonian boundary values problem (BVP). More specifically, the cost function in the minimization procedure is the time required for the drone to traverse the given waypoints while avoiding a number of forbidden zones, assuming a constant cruising speed. The module converts the geodetic coordinates of the waypoints into their universal transverse mercator (UTM) or planar form to make them compatible with the BVP code; it also manages the presence of wind as an input vector field. The image on the left in the figure below shows an example of an optimal flight path (solid line) joining two waypoints while avoiding three areas (encircled by ellipses) that are under the influence of a wind that has a constant direction but variable intensity (green arrows). The picture on the right shows the course angle as a function of time which corresponds to the optimal trajectory, and which is also available as an additional output of the module.

Fig. 4 - Two different trajectory models can be chosen: (a) minimum jerk trajectory, to reduce battery consumption and oscillation and (b) Hermite cubic splines to mimic the flight of a fixed-wing drone

The resulting waypoints are expressed as geodetic coordinates. Trajectories based on algorithms such as minimum jerk splines and Hermite cubic splines are generated from the list of waypoints and the specific time in which each waypoint must be reached. The choice of the trajectory model depends on specific objectives, such as reducing battery consumption and oscillation phenomena, or minimizing the deceleration and acceleration at waypoints by using flight profiles that are very close to those of fixed-wing drones.

The Manager module also collects information from the camera and other sensors for the subsequent stages of the workflow. A specific module synchronizes the images captured by the camera with the position (image geotagging) and the drone's heading information relative to the time stamp of the snapshot. The camera is mounted on a stabilized 3-axis gimbal to attenuate vibration noise during flight and is constantly oriented in a nadiral position.

The module for pedestrian detection receives the images from the Manager module and returns a set of bounding boxes concerning the risky zones to be avoided during flight or landing. Since the input consists of images in the three RGB channels taken from the camera, the most effective and efficient approach to use for detection is based on Convolutional Neural Network models, a particular class of feed-forward artificial neural networks that are at the forefront of many Computer Vision tasks, including object classification and recognition; facial recognition; pattern recognition in video; etc.

Fig. 5 - Example of pedestrian detection using YOLO on an image frame from a benchmark dataset

Object detection is the recognition of a variable number of objects within digital or video images, along with an accurate estimate of their location within the image. This localization is achieved by predicting the coordinates of the bounding boxes that surround each detected object. To satisfy the need for real-time responses in a limited computing environment (such as that of a drone) without sacrificing detection accuracy, the TinyYOLO model is used . "You only look once" (YOLO) is a simple approach based on a single convolutional network that provides excellent predictive abilities and detection speeds with real-time object detection.

The bounding boxes returned by the detection module are geo-referenced in order to obtain geodetic coordinates. This step is performed by applying the typical logic of a 3D rendering pipeline, like the one found in near real-time simulation (for example in 3D games), appropriately inverted to transform the image coordinates into world coordinates.

The bounding boxes serve as input to the real-time optimization module, which generates a new flight plan by modifying the original one to avoid the areas represented by the bounding boxes. The selection of the optimal path is inspired by algorithms drawn from robotics and interactive games.

Basically, the problem of optimization requires the system to find the best route from one point to another (in our case from the drone's current position to the next way-point) keeping in mind the forbidden zones and the travel time. The approach follows graph theory and is based mainly on three algorithms: (i) Breadth First Search, which is important for finding a route, and for generating procedural maps, distance maps, flow paths and other types of map analysis; (ii) Uniform Cost Search, which identifies the priorities on the routes to be analyzed; (iii) A* search algorithm, which is an informed search procedure that is able to optimize the cost of a route by performing an efficient search within a wide range of solutions.

Preliminary experiments show that the workflow for route optimization is promising both in terms of effectiveness and efficiency. The most time-consuming modules, in particular the detector module, are able to perform accurate detection in about 100ms and the subsequent A* algorithm takes some extra 30ms (reference hardware platform ODROID – XU4).
However, the research project is an ongoing activity that requires several stages of development and testing, which are the main focus of the ongoing research efforts.

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For more information:
Corrado Mencar - Università degli Studi di Bari A. Moro
corrado.mencar@uniba.it