L'HOMME CONNECTÉ

Drone autonome pour l'intervention humanitaire
Autonomous Drones for Humanitarians Operations

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Résumé
L'information est un point crucial pour correctement gérer les conséquences des catastrophes naturelles. En particulier, rassembler cette information afin de décharger les équipes de secours et guider ces dernières vers les points les plus pertinents, sont deux problématiques encore peu abordées dans lesquelles les minis-drones ont un rôle à jouer. Toutefois, la manipulation de ces engins n'est pas aisée, et peut demander du temps que n'ont pas les équipes de secours. Ainsi, notre contribution est de rendre les drones plus autonomes dans leur vol (scanner une zone en évitant les obstacles), et dans leur mission (identifier les groupes de victimes). Enfin, il convient de souligner que nos travaux permettent une autonomie à la fois à l'extérieur comme à l'intérieur de bâtiments.

Abstract
Information plays a key role to correctly handle consequences resulting from natural disasters. In particular, relieving rescue teams from gathering that information, and automatically guiding rescue teams to most urgent sub-situations is an open issue in which mini-drones can play a key role. Yet, the control of such vehicles is not straight forward to users and can be time consuming. Thus, our contribution is to bring autonomy to drones: to fly autonomously, e.g., scanning and covering a given area, and to realize some tasks (e.g., identifying groups of disabled persons). Last but not least, autonomous drones shall be able to perform both outdoor and indoor missions.

1. Introduction

When a natural disaster occurs in a populated zone, a fast and effective organization of the disaster management is necessary to assist the population, to reduce the number of victims and to limit the economic impact [1-4]. At all phases, one of the first actions to be taken is to set up a disaster cell for coordination. A non-optimal organization causes supplementary losses and delays to come back to, or even prevent, normal situation. (http://www.un-spider.org/).

During such an event, maintaining a communication link between victims on one hand and the various actors of the response on the other hand is crucial. This link remains essential even in non-catastrophic circumstances, for instance, a major black-out in a network (electricity, water, etc.). Emergency management starts both with search and rescue, and then with the stabilisation of the overall disaster situation. At any time, the rescue teams need immediate and relevant information concerning the situations they have to face: disaster evolution, surviving persons, critical zones, access to refugee camps, spread assistance tools, etc. Required information is provided by a comprehensive data handling system, called the Geographical Information System (GIS) fed by files generally produced by organizations and space agencies involved in the International Charter "Space and Major Disasters".

The detection and the monitoring of the impact of natural disasters are mainly performed by space borne and air borne remote sensing surveys through radio and optical instruments. Due to limitations in the time window observation attached to optical instruments (i.e. no observation at night or in presence of cloud cover), radio observations (available ~ 24/7 and relatively insensitive to atmospheric conditions) are particularly useful during the "Response phase" of the disaster management cycle where information must be delivered to the disaster cell with a as short as possible delay [5-7]. As explained in [3], new approaches and the use of new technologies are required for more efficient risk management [3], before, during and after a potential crisis. Every specific action at each step of the crisis must be taken into account and dedicated tools are necessary to handle them. New methodologies are also needed to conceive assistance systems that shall rely on telecommunication tools, remote sensing for instance [8], and space/temporal-oriented databases which implement dedicated rules regarding risks [9].

In this context, Information-Technologies (IT) oriented communications is, nowadays commonly used in risk management studies [10, 11]. Thus, many studies and specific researches yield to renew the range of possibilities, although the efficiency still remains to be assessed. Many technological innovations (social networks, wireless Internet, Internet of thinks, robots, drones, etc.) are now common in our society. Do they forge a true new trend for crisis and risk managers, taking into account their vulnerabilities? How can they support the activity before (prevention), during (management) or after (resilience) the crisis? The usage of drone in that scope is discussed in the rest of the paper. In particular, we present several scenarios in which drones could play a key role, and we present early results we obtain to reach a good level of autonomy, and thus discharge rescue teams from a time-consuming drone manipulation.

2. Drones

Drones, also known as UAV (Unmanned Aerial Vehicle) are flying machines which are remotely controlled. They are generally used for surveillance purposes and to collect information. Drones are currently mostly used for outdoor applications, and, apart from the user interaction, their guidance is GPS-based.

The popularity, availability and range of applications attached to Micro Air Vehicles (MAV) - especially quadcopters - have been steadily increasing over the last few years. MAV research connects a diverse range of topics such as control systems, computer vision, sensor fusion and artificial intelligence. While the mechanical performance of rotor-driven models has long been satisfactory, enabling applications like localization, mapping and autonomous flight using minimal sensors and infrastructure still presents various R&D challenges: Especially for MAVs, on-board sensors as well as processors should be inexpensive, but also lightweight and energy-efficient. Applications must therefore be able to cope with limited and noisy inputs. At the same time, either their complexity needs to be compliant with the on-board processing, either their robustness against signal latencies and interruptions has to be compliant with remote operations.
Since they are naturally much smaller than regular drones, mini drones are more likely to be used for indoor applications. Unfortunately, the GPS signal cannot be efficiently used inside buildings, and so, mini-drones must permanently be remotely controlled, which strongly reduces their interest.

Among all the technological objects of our modern environment, the drones have an incredibly high potential for offering fast and efficient responses to these issues, even if some difficulties must be tackled:

- The question of autonomy is more and more important. New applications, such as the intervention in hostile environments or drone operations, involve effective autonomy both on the energy points (duration of the mission) and of the control-command (decisional autonomy).
- To develop a drone adapted to these above described situations, the following hardware and software architectural issues have to be addressed: which algorithmic architectures to adopt? Which embedded system configuration is the most suitable one?
- The man-machine interface (HMI). What is the GUI optimizing the perception of a victim, being in front of the drone, e.g. how can a drone reassure the person or give him/her information about relief?

The problem could be decomposed into three main categories which are:

- The energetic autonomy. In others words, how long can last a mission without a return to the base station.
- The operating autonomy (on-board intelligence, real-time decision making), deals with both the robotics fields, and signal-image processing for detection, e.g. obstacles.
- The definition and the design of antennas embedded intended for the detection of electromagnetic emission, e.g. the ones of mobile phones (GSM, UMTS, etc.) and more generally wireless networks (Wi-Fi, Bluetooth, etc.).

3. Autonomous navigation

Previous work with specialists from the disasters intervention (French "Protection Civile", MSF[1], ICRC[2], etc.) allowed us to formalise three primordial needs for rescue teams. The effectiveness of these operations depends on the speed and accuracy at which they can be carried out:

- The detection and following of people/victims impacted by the crisis,
- The identification of the possible access (e.g. safe roads, paths) to the disaster area and to the victims,
- The continuous assessment of the evolution of the situation concerning the impacted area.

[1] *MSF : Médecins Sans Frontières.*
[2] *ICRC: International Committee of the Red Cross.*

To reach those objectives, it is necessary to design an autonomous system whose deployment requires neither scientific nor technological skills. Indeed, the drone must have a very high degree of autonomy in order to conduct its mission.

Indoor navigation is globally easier than outdoor. Difficulties attached to the weather like rain and wind do not exist. Moreover, the mini drone might be aware about the map of the building and the nature of main objects inside it. On the top, we can envisage as soon as now to use some RGB-D cameras that is almost impossible outdoor. The main difficulties in indoor are possible collisions with people, doors, and the limited space to navigate.

In this context, the navigation requires an on-board intelligence. It should notably be able to fly close to the ground - the latter potentially being chaotic - acknowledging automatically the obstacles in the trajectory, and with minimal actions from the drone operator. In previous works we provided autonomous navigation features to drones relying on both (1) the definition and implementation of special flight maneuvers (advanced control) and (2) the definition and implementation of image analysis algorithms in order to reconstruct the 3D environment or to track information, objects or people [12, 13].

Figure 1: *Left picture: a drone can follow a line on the floor with no human control (indoor navigation). Right picture: the drone must also be able to navigate autonomously outdoor.*

Three classes of functionalities will be used to illustrate the interest of the response to the above challenges:

- Visual scanning of the zone for establishing an emergency mapping (scenario 1).
- People detection with a distinction between adults and children (scenario 2).
- Detection of EM waves emitted by mobile phone, Smartphone or Tablet terminals in order to identify the most probable rubble under which rescue teams are most likely to find victims (scenario 3).

These three abovementioned scenarios are progressive in their complexity, and also progressive in the support they could provide to rescue teams.

In the first scenario, a drone must fully scan and cover a given area (e.g., all corridors of a building, or an outdoor field of operation). The drone therefore requires to autonomously fly in various conditions (narrow corridors, devastated buildings, etc.). By “covering”, we mean that the expected output is a map of the explored area. The covering capability is reused in the next two other scenarios.

In the second scenario, the drone has to identify groups of disabled persons, and to make a clear distinction between adults and children. That distinction makes sense because the supports that rescue teams have to provide to adults or children strongly differ. Such triage must be compliant with international and local ethical policies. Following (e.g. tracking) a specific group might also be of interest for sorting and understanding their velocity and expected position in a near future.

Finally, the last scenario intends to guide rescue teams to the most probable locations where to go and search for victims, in general, after an earthquake, based on the localization of personal connected objects. In particular, drones could embed several printed antennas with the goal to trace the source of emissions of these connected objects.

To reach this last objective, it is required to develop a new airborne solution for detecting and mapping the position of people, sometimes even buried victims of disaster. The main idea is to make an image of the ground using an antenna, carried by a drone flying at a very low altitude. This is now possible thanks to the increase in the processing speed of the processors, a lower energy consumption of active components including RF, and larger capacity of storage memory in a smaller volume which is a significant factor for onboard equipments. These must be:

- Multi-band to not neglect any radiation radio source.
- Strong directivity to target with precision the source of emission.
- Low weight.

Two approaches are usable. The first so-called 'static' will consist in designing an antenna whose directivity, gain adjustment weight performance will be optimal according to the available weight and space onboard the drone. The drone will thus be able to detect an EM emission when being in vertical position. It can then record and transmit the identified coordinates of flight through another miniature antenna to a centre of command (Headquarter). The second so-called 'active', will allow, in a single pass, to cover a wider geographical area. To do this, active electronics will achieve a space electronic scanning of an angular area around the vertical to the aircraft, in the plane perpendicular to its displacement. In the case of detection, the drone will then forward its coordinates of flight as well as the angle of signal arrival to the PC. Here we find the spirit of 2D synthetic aperture antennas but in a purely listening approach.

This technique is therefore innovative in its design and for the resulting performances:

- No high bandwidth but a multichannel approach to be effective.
- Not continuous emission and thus a much smaller power consumption.
- No problem of purity of binding emission frequency.
- Simplicity of the Radar.
- Low cost.
- Flying at very low altitude: < 10 meters.
- Capacity to go back to areas where a refinement is needed, according to first results or to the strategy.
- The possibility of evolution of mission of antennas, area covered resolution change, etc.

Again, to support those three scenarios, the drone must be autonomous during its fly, and for the tasks it is entitled to. For reaching a good level of autonomy, two technical contributions are now detailed: the environment identification, and people identification. Both contributions were developed in the scope of the *drone4u project* [14].

4. Environment identification

To be able to autonomously navigate within buildings, or outside of collapsed building, going from one GPS point to another one is not feasible, just because too many (eventually moving) obstacles may be present and source of collisions. Reaching a good level of autonomy therefore requires to correctly identify the environment. In the scope of autonomous cars, the issue is not the same since this is possible to embedded many various sensors (e.g., camera, Lidars, etc.). Because of the power consumption and weight limitations of drones, we therefore have assumed that only one 720p camera was onboard the drone. Thus, we propose to emulate more complex sensors by evaluating monocular images before and after a modification in flight position. While saving one camera's weight and power consumption, this approach also introduces algorithmic challenges as well as some inherent limitations. Therefore, our work consists in reconstructing the environment of the drone in 3D, and to navigate according to that reconstruction. Two different approaches are investigated:

- The drone makes a dense 3D scan. That approach relies on the computation of an estimated distance for most pixels of images. This mode of operation unfortunately implies the use of an exclusive and dedicated flight control in order to virtually create a vertical stereo camera through a change in altitude (see figure 2). Because regular flight needs to be interrupted for this maneuver, results are dense in space but sparse in time.

- On the contrary, sparse3D may be used continuously during regular flight and therefore is our preferred method of perception. It relies on the spatial locations of few hundreds of distinct feature points in images, see figure 3. Their accuracy largely depends on the drone's motion: Vertical and sideways movements are particularly beneficial, which is why our associated control strategy superimposes an oscillation in those directions, hereby creating a corkscrew-shaped flight trajectory [16].

We implemented and tested the two approaches (Sparse3D and Dense3D) with an ARDrone2. The cost of an ARDrone2 is very low (around 300 Euros) [12] which demonstrates the possibility to easily transpose our results to more expensive platforms. In our approach, images are sent by the drone to a remote PC that computes flight commands from image processing algorithms and then sends back flight commands to the drone. Both types of autonomous flights with environment perception can be seen in on online video in the scope of indoor navigation [14].

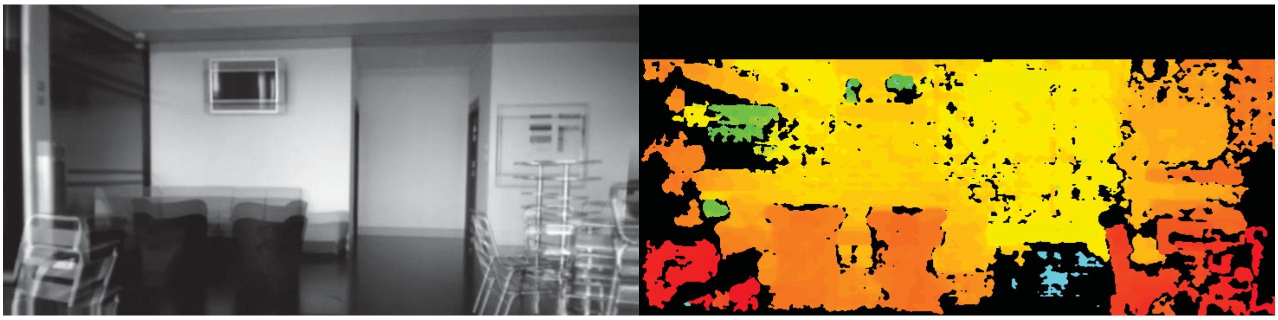

Figure 2: *Dense3D reconstruction. The overlayed rectified images before and after the height change visualize the precision of the estimated camera motion (left). Therefore, any standard implementation for distance reconstruction, e. g. [15], may be used without modification (right).*

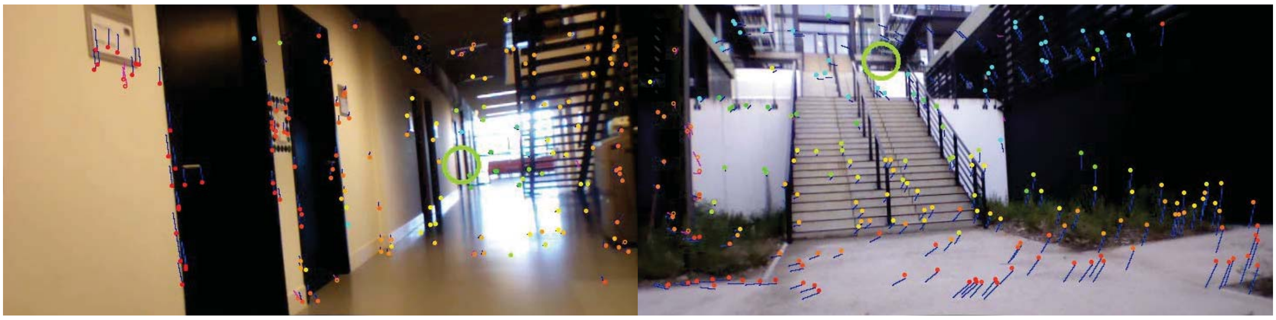

Figure 3: *Sparse3D indoor (left figure) and outdoor (right figure) reconstruction based on a few dozens of points. Blue/purple lines show optical flow vectors consistent/conflicting with the camera's motion. The points in colour represent their longitudinal distance – red indicates 1 meter or less, cyan for 10 meters or more. A larger green circle marks the flight direction targeted by the drone, which is computed according to the furthest possible distance with no potential obstacles.*

5. Group identification

Identifying groups of victims is necessary so as to better predict the assistance to provide. For such a complex task, several subtasks are defined:

- To detect people. Our approach is based on classical Histogram of Gradients (HOG) to extract Regions of Interests (RoI).
- To evaluate the composition of the group (adults, children).
- To estimate group's displacements.

It requires to be able to focus on a given person of that group in order to follow him/her for a while so as to estimate the direction/destination of that person. To do so, we re-use the algorithm described in [17] with some basic customizations. This algorithm is composed by two main blocks: a detector based on Histogram of Oriented Gradient (HOG) descriptors and linear Support Vector Machines (SVM), and a tracker which is implemented by an adaptive Rao-Blackwellised particle filter (RBPF).

Histogram of Oriented Gradients (HOG) is a popular feature descriptor in people detection in video surveillance [18]. Images are divided into blocks and then into cells for which histogram of gradients are calculated. Local histograms are composed of bins corresponding to different orientations, with a weight based on magnitude. Then support matching Vector (SMV) that are a very popular and efficient classifiers are used to separate patches into two categories: human against anything else. A training set is required in order to maximize positive detections while minimizing missing and false positive detections. A particle filter is used to track detected people. In [17], the prediction phase is based on a simple linear motion model; the estimate of the new state of each particle is a linear extrapolation of the previous state plus Gaussian noise. The update phase is based on people detections. The resampling phase is based on Kullback-Leibler divergence (KLD) that offers the advantage to limit the number of particles and consequently reduces the computational cost.

The approach has been evaluated in various conditions: inside buildings, outside buildings, in different weather/lightning conditions (sunny, windy, cloudy, etc.), and with groups of different sizes, and with crossings of other persons between the camera of the drone and the person to follow (occlusion). As for the environment recognition, we have experimented the algorithms for a low-cost drone (ARDrone2).

Figure 4: *Tracking a person. On the left picture, a HOG transform is used to detect a region of interest. In the right picture, a particle filter is used in the region of interest to know whether the same person is being followed.*

Many videos concerning this article are available on http://drone4u.eurecom.fr/ .

6. Conclusion

Among all the high tech objects of our modern environment, drones have an impressive high potential to offer fast and efficient responses in rescue contexts, even if some difficulties must be tackled. The new applications, such as the intervention in hostile environments requires an effective autonomy of mini drones concerning the energy (duration time of the mission) and the control-command (decisional autonomy). Hardware and software issues have to be addressed: which algorithmic architectures to select and implement? Which embedded system configuration is the most suitable one? Which kinds of GUI are the most appropriate from victims, being in front of the drone? How can a drone help to appease people in critical conditions or to provide useful information?

The design of a civilian UAV intended for intervention in post-disaster conditions is an important challenge. The gain in autonomy of mini drones, coupled with the use of non-conventional sensors such as Lidar, IR camera, etc. will strongly increase response capabilities – e.g. people detection, rapid mapping, damage estimation, etc. - of the rescue teams on the ground. To be effective, these customized sensor systems must perform their duties in an independent manner and transmit their data. This information will then be inserted in the decision making cycle. It is also imperative that the manipulation of these systems does not require special skills. This condition is a sine qua non condition which explains the rationale of our focus on autonomous flight and mission. Without that capacity, it would not be possible to correctly integrate these new tools within the rescue teams.

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