SAR.Drones: Drones for Advanced Search and Rescue Missions

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***Abstract*—This paper presents our framework based on visual exploration of disaster areas (i.e. after an earthquake, a tsunami or an industrial accident). It is meant to help rescue teams to locate hotspots (i.e. half-buried person or broken and dangerous canalization) and to maintain an Internet connection for them. Indeed, our solution uses several small autonomous drones (or UAVs, Unmanned Aerial Vehicles) to explore the area with embedded webcams, inform rescue teams about observed events, and eventually provide a substitution network to them.**

***Index Terms*—UAV, drone, ad-hoc network, substitution network, search and rescue, exploration**

I. Introduction

UAVs (or drones) have long been limited to the military sphere. Nowadays, technology improvements allow civilians to work and perform experiments on real drones (far from the military ones, but yet having a lot of potential). Thus, drones are emerging in the field of public research, and it is a great opportunity to discover and investigate new possiblities in terms of networking and mobile communications. Indeed, there are scenarios in which wireless communications are at the same time nonexistent and critically needed, and drones could be a great help in those cases (e.g. in case of an earthquake). Drones are a good solution because they can cross a wide area without having to touch the ground, and thus can be used to explore the wreck after an earthquake.

Our proposed framework involves the utilization of several small UAVs in such context. This implies the development of a cooperation algorithm that will allow the fleet of drones to efficiently cover the whole area and report detected events to rescue teams.

This paper is divided into six parts: Section 2 lists and details some related works on autopilot mechanisms for UAVs and search and rescue applications. Section 3 introduces our framework and explains several exploration schemes for the drones. Then, Section 4 presents the network protocols we developed and implemented in our framework. Auto-pilot algorithms and real test results are detailed in Section 5. Finally, Section 6 concludes this paper and introduces planned future works on our framework.

II. Related Work

Several works already investigate using drones for video surveillance [1] or real-time response to disasters [2]. [3] presents the current state of research on unmanned aerial vehicle remote sensing and its applications. Also, some works present path following schemes and autonomous flight control systems for UAVs [4] [5] [6] [7].

[2] introduces a research that is part of AirShield (Airborne Remote Sensing for Hazard Inspection by Network Enabled Lightweight Drones). The main goal of this project is to locate and analyze uncontrolled emission of hazardous substances in the troposphere (e.g. when a chemical plant is on fire). In this context, a fleet of drones are sent in the potential toxic cloud, make measurements, maintain a mesh network and send data to the ground control station.

[4] provides a good explanation on autonomous flight control systems for plane-like drones. The corrective maneuvers employ the Bank to Turn (BTT) approach. In the context of exploration and video surveillance, the authors applied the concepts of common airplane autopilots to UAVs. They provide a lightweight solution based algorithms and mechanisms used in common airplanes, adapted to plane-like UAVs. They performed advanced simulations of their solution, and demonstrated the efficiency of their algorithm.

III. Exploration Schemes

This section explains the context of our framework and presents the different exploration schemes we envisaged.

We place our framework in the context where rescue teams arrive just after a disaster (tsunami, earthquake, hurricane, explosion,...). We propose that a member of the rescue team launches the deployment of a fleet of drones near the stricken area. Then, after being informed of the area to explore, the fleet organizes itself so that it can cover all the area quickly and efficiently with embedded webcams.

We investigated two main ways of exploring a rectangular area with a fleet of small UAVs: creating a "squadron" of drones that fly in formation, or dividing the area into rectangular sub-areas, each sub-area being assigned to a drone.

A. Squadron exploration

The advantage of the "Squadron exploration" is that the drones fly close to each other (see Figure 1). Thus, all drones can easily converge to a detected event when one of the drone detects one. However, the drawback of this solution is that the provided substitution network does not cover the whole area to explore: as the drones fly close to each other, they can easily communicate with each other, but the squadron is concentrated in a small area and is isolated from the remainder of the network.

In order to determine the maximum area that can be explored with a given number of drones in a given amount of time, we need to evaluate the length of the trajectory for one of the drones.

Before being able to calculate this length, we have to determine the shape of the squadron, i.e. the number of lines we split the drones into (see Figure 1). In order to get a compromise between WiFi coverage and exploration efficiency, we distribute the drones uniformly, trying to equal the number of rows and the number of drones per row (e.g. with 4 drones we split them into 2 rows).

Also, the spacing between two rows of drones is put to a maximum, so that a drone flies straight as long as possible, while also keeping the WiFi connection. Hence this maximum distance chosen as the spacing between the rows is the WiFi range.

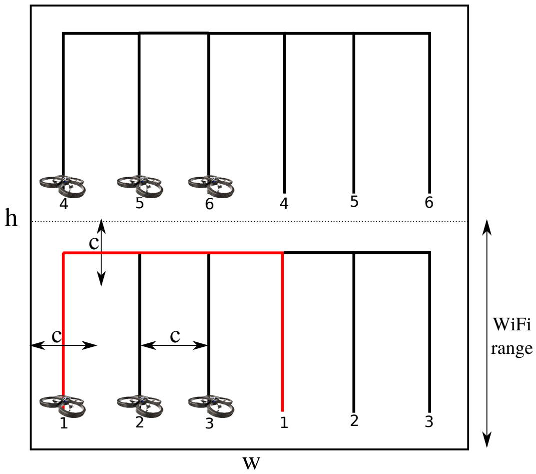

Figure 1. Representation of the exploration scheme

Figure 1 shows the exploration scheme for 6 drones (2 rows of 3 drones each). The red path shows the trajectory for drone 1. Now that we determined the shape of our squadron, we can calculate the length $d_{squadron}$ of the trajectory for one of the drone (we assume that the length of the trajectory is the same for all the drones). Hence, we deduced the formula that gives the distance of the path. We also determined the coverage provided by the WiFi ad-hoc network of the drones.

B. Independent exploration

The advantage of the "independent exploration" is that the substitution network provided by the drones covers a wider surface. Moreover, as for the squadron exploration, this ad-hoc network is very stable (the distances between the drones remain constant). However, the drones are farther from each other, and this implies a larger delay when they need to gather at a given location.

The areas covered by the drones with their WiFi interfaces are almost distinct (they overlap only for the drones to be able to communicate with each other). As a consequence, the overall WiFi coverage is linearly linked to the number of drones. Hence, Figure 2 compares the WiFi coverage for squadron and independent explorations, with $w_{range} = 100\,m$ and $c = 20\,m$. We observe that independent exploration provides a far better WiFi coverage.

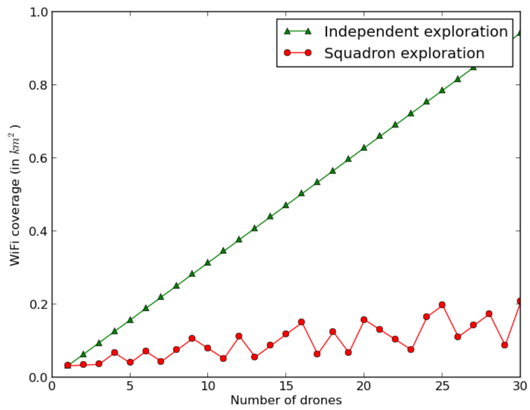

Figure 2. Comparison of WiFi coverage

As a conclusion, regarding the analysis of these two scenarios, it appeared to us that the "Independent exploration" was best suited to our needs: it provides a good WiFi coverage, it explores the area efficiently, and the drawback (the distance between the drones) seems negligible in comparison to the advantages. As a consequence, we implemented this scheme into real UAVs, and performed some tests and measurements (see Section 5).

IV. UAV's ad-hoc Network

This section details the mechanisms involved in the ad-hoc network created by the drones. The protocol we developed allows to spread the information when an event is detected, to auto-organize the fleet so that the drones are aware of the position of each others, and to provide a substitution network to rescue teams.

Optimized Link State Routing (OLSR) protocol, the well-known ad-hoc network routing protocol, has been ported to the drones, in order for them to use multi-hop communications and maintain links states. Each drone periodically broadcasts its position, along with some status information, via WiFi. Hence, all neighbors receive the data and can avoid collision or adapt their exploration scheme.

When a drone detects something, the information is critical and should be assured to reach the expected receiver. First, when a drone detects something, it immediately sends the information via a special packet, and uses multi-hop communications to reach the ground station. When the information reaches the ground station, this latter can itself disseminate the information via their traditional means of communication (e.g. an operator can speak to rescue teams via long-range radio devices). If OLSR cannot find a route to the ground station, the packet is disseminated inside the drones network, so that nearby rescue teams can receive the information. In order to disseminate efficiently without flooding the network, we can use the enhanced version of Multi-Hop Vehicular Broadcast (MHVB) [8] protocol.

V. Proof of Concept

This section presents how we tested our framework in a real environment. We detail the platform and the auto-pilot mechanisms we implemented on it.

In order to test our framework on a lightweight and low-cost platform, we chose to use four Parrot AR.Drones 2.0. These drones already integrate an algorithm that can detect specific tags (e.g. a black roundel with a black line on a white sheet) on camera images. Thus, we enlarged the provided tag and placed several of them on the ground, so that vertical cameras can detect them. This was meant to emulate an event that has to be detected by the drones (e.g. a person who toke refuge on a roof during an inundation). Because these UAVs are smaller than the ones that would be used in real scenarios, we scaled our use case to the size of the drone. Indeed, as our UAVs' cameras coverage area is small ($c = 6\,m$, we have to fly close to the ground because of the poor quality of the embedded webcam), we reduced the WiFi range in proportion. Hence, with bigger UAVs we will have a normal WiFi coverage and a larger UAVs' cameras coverage, and the ratio $\frac{c}{w_{range}}$ will stay the same. We assumed that an UAV deployed in a real scenario will cover 50 meters ($c = 50\,m$). Then, $\frac{c}{w_{range}} = \frac{50}{100} = 0.5$. Hence, we reduced the WiFi range of our AR.Drones to 12 meters. This scaling also has the great advantage to require a smaller space for testing.

All drones need to be autonomous: they have to be able to explore without a constant connection with a ground base station. By default the Parrot AR.Drones 2.0 do not allow that. Parrot provides an SDK that allows to control the drone from a PC, a tablet or a smartphone, but always with remote commands from a distant device. We modified and adapted this SDK so that it produces a library that can be uploaded to the drone. Hence, we can code the same way we would do with the official SDK (using the same primitives for controlling the UAV), but then compile the program for the drone and upload it on the UAV, so that our drone is fully autonomous.

After we rendered the drone fully autonomous as described in the previous paragraph, we developed a robust auto-pilot that can follow the paths required for automated exploration. We based our auto-pilot algorithm on the mechanisms presented in [4]: we used a 2-dimensional representation of the position of the drone according to the expected trajectory using Serret-Frenet frame. Then, we implemented the formulas of [4] in our auto-pilot, especially (1) that determines the heading command χ_{com} using the representation shown in Figure 3. t_c is an arbitrary parameter that controls how "smoothly" the drone locks on the trajectory. A greater t_c implies smoother movements. However, [4] presented an auto-pilot for plane-like drones, and AR.Drones are quadrucopters. Thus, we adapted the Bank To Turn (BTT) maneuver to our drone's mechanical constraints.

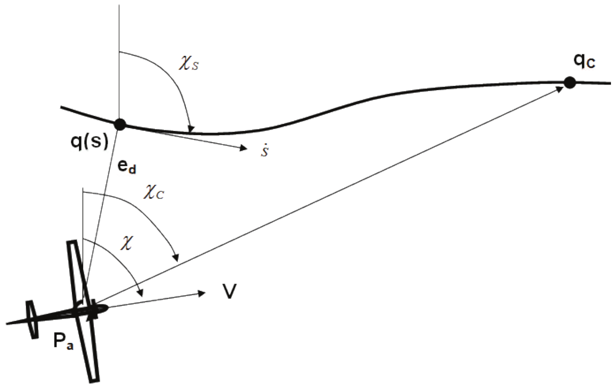

Figure 3. Corrective course direction

$$\chi_{com} = w_c \cdot (\chi - \chi_c) + (1 - w_c) \cdot (\chi - \chi_s) \qquad (1)$$

where

$$w_c = \begin{cases} 1 & \text{if } e_d > t_c \cdot V \\ \frac{e_d}{t_c \cdot V} & \text{else} \end{cases}$$

VI. Conclusion

This paper presented an innovative and complete solution for search and rescue in disasters, using small UAVs that communicate together. We analyzed several exploration schemes, implemented the most efficient one on real UAVs, and performed real test with four drones. This framework is open-source and provides more features than existing commercial frameworks.

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