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Drone-borne GPR design: Propagation issues

Conception GPR pour drone : propagation

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A B S T R A C T

In this paper, we shall address the electromagnetic wave propagation issues that are critical to determining the feasibility of a drone-borne ground-penetrating radar sensor for humanitarian applications, particularly in the context of disaster management. Frequency- and polarization-dependent scattering, attenuation and dispersion of radar signals penetrating into the sub-surface region will determine the applicability of a drone-mounted radar sensor capable of registering radar echoes for observing and monitoring sub-surface features. The functionality of the radar will thus be assessed depending on key radar parameters that include the central radar frequency, the modulation depth, and the mode of radar operation (pulsed FM, FM-CW), the antenna type, the available power-budget.

In the analysis to be presented, the radar equation, together with the aforementioned propagation effects, will be used to simulate the signal strength of radar echoes under different conditions arising from the chosen key-radar parameters and the assumed physical properties of the sub-surface earth medium. The analysis to be presented will indicate whether or not the drone-borne ground-penetrating radar is a feasible system and if it could be constructed with the technologies available today.

Taking into account the strict constraints involved to design drone applications for Public Protection and Disaster Relief (PPDR), the ideas developed hereafter are both prospective and exploratory. The objective is to see if a solution can be found in the near future.

R É S U M É

Dans cet article, nous allons aborder les problèmes de propagation d'onde électromagnétique qui permettra de déterminer la faisabilité d'un capteur radar à pénétration de sol, embarqué sur un drone, destiné aux applications humanitaires, notamment dans le cadre des catastrophes. L'étude de la fréquence, de la polarisation, de la diffusion, de l'atténuation et de la dispersion des signaux radar pénétrant sous la surface permettra de déterminer l'applicabilité d'un capteur sur drone. La fonctionnalité du radar est donc évaluée en fonction de paramètres clés, qui incluent la fréquence radar, la profondeur de modulation et le mode de fonctionnement des radars (pulsé FM, FM-CW), le type d'antenne, en fonction du budget puissance disponible.

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Dans l'analyse présentée, l'équation radar, ainsi que les effets de propagation susmentionnés, serviront à simuler la puissance du signal des échos radar sous différentes conditions découlant des paramètres clés choisis et les propriétés physiques du milieu sous la surface. L'étude a pour objectif de démontrer si le système est réalisable et s'il peut être construit avec les technologies disponibles aujourd'hui.
En raison du contexte très contraignant des applications pour la protection du public et secours en cas de catastrophe, les idées ici développées ont un caractère tout à la fois prospectif et exploratoire, l'objectif étant d'examiner si, dans un avenir proche, une solution se dessinerait.

1. Introduction

When a natural disaster occurs in a populated zone, a fast and effective organization of disaster management is necessary to assist the affected population, reduce the number of victims, and limit the economic impact [1]. At all phases of disaster management (pre-disaster, response, post-disaster), one of the first actions to be taken is to set up a 'disaster cell' for coordination. The detection and the monitoring of the impact of natural disasters on terrain are mainly performed by space-borne and air-borne radio and optical instruments [2,3]. In contrast to limitations in the time window of observations attached to optical instruments (i.e. no observation at night or in the presence of cloud cover), radio observations are available 24/7 and relatively insensitive to atmospheric conditions: these are, therefore, particularly useful during the 'response phase' of the disaster management cycle, when information must be delivered to the disaster cell with the shortest possible delay [4–6].

Unmanned Aerial Vehicles (UAV) may bring significant improvements with respect to these issues. They can be easily equipped with various kinds of sensors in addition to optical ones depending on the mission. Their low altitudes make it easy to observe below a cloud cover. Finally, search and rescue teams may carry UAVs and deploy them upon need on site, for instance to explore some flooded area in order to find a stable path to victims, or a ruined building. In this respect, UAVs extend the exploration range of rescue teams, while at the same time they improve the latter's safety in areas that may be dangerous. The senseFly UAV has, for instance, demonstrated the automated mapping capabilities of small drones and how they are able to save the lives of the victims in the aftermath of the Haiti 2010 earthquake, by enabling the authorities to quickly draw maps of the devastated areas [7].

Developing and integrating autonomous features into the UAV is key to this application. Indeed, the UAV is likely to be in situations where it will be unable to communicate with the control centre, either sporadically due to interferences, or for extended periods of time if it explores the terrain behind obstacles or beyond the reach of any radio relay. Depending on the real-time requirements, the communication capabilities, and the complexity of the sensors deployed, the data sensed will either be processed appropriately in terms of navigation and sensor deployment, or data fusion algorithms have to be developed [8]. Autonomy does not mean that the UAV will not be controlled remotely, for instance in order to zoom-in on some scene that would be of interest to rescue teams even if it were not considered so by the UAV itself.

As explained in [9–11], new approaches and the use of new technologies are required for a more efficient risk management, before, during, and after a potential crisis. Every specific action at each step of the crisis must be specifically considered. For that purpose, new dedicated tools and methodologies are required to better handle crisis situations.

1.1. Related works

The numbers of event-related cases, where drones have already been useful in humanitarian settings, are many; the ones described here are just a small subset of these. Danoffice IT has a commercial drone solution for disaster response [12]. It was already used in real operation sites such as the typhoon Yolanda in Tacloban, Philippines, where it helped in the identification of the operations site, and in the identification of usable roads. In the same disaster event, the CorePhil DSI team [13] used a fixed wing drone, eBee, to capture aerial imagery of downtown Tacloban. These images were further analysed through crowdsourcing and helped in the generation of the most detailed and up-to-date maps of the region. These maps were used by different humanitarian organizations, and even by the Filipino Government.

Controlling a fleet of drones is an established and on-going topic as well. In fact, it is a well-studied subject in the military context. However, even never mind the fleet control proposals are basically meant to help humans to control the fleet rather than having an autonomous fleet. For example, Cummings et al. [14] proposed an automation architecture to help humans in the supervision of a drone fleet, but the drones are not fully autonomous and it is the human operator who always decides drone missions. The same comments are valid for other works in the field, e.g., the work of Arslan and Inalhan [15], where the whole effort relies on helping one operator to control multiple drones.