Issues of indoor control of a swarm of drones in the context of an opera directed by a Soundpainter

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ABSTRACT

Among the many issues one encounters today with drones, and especially with swarms of drones, positioning has become more and more crucial. Even though technologies such as GNSS and sensor based location systems have become mature, they are only efficient, *i.e.* accurate, outside of buildings and in environments that are not adverse (no jamming). In this paper, to go beyond the state of the art, we present the issues of indoor and adverse locations and provide retex based on our previous and current research work. Our use case is an indoor show using a swarm of drones directed by a Soundpainting artist.

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CCS CONCEPTS

• **Computer systems organization → Embedded systems**; *Redundancy*; Robotics; **Fault-tolerant network topologies**; • **Networks** → Network reliability; • **Human-centered computing → Gestural input**.

KEYWORDS

Drones, swarm, indoor positioning, GPS denied environment, Soundpainting, human drone interaction, Smart and Empowering Interfaces

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(1) Give the drone the location of the target point it must go to.
(2) Make it possible for the drone to determine its precise location.
(3) Make the system self contained, *i.e.* we do not want (as far as possible) the drone to rely on some external setup, it must be autonomous.
(4) Make the overall system must be resilient to the loss of communication.

Figure 1: The four main challenges that we address

INTRODUCTION

Drones are becoming more and more common in many areas such as search & rescue, surveillance, etc. They are used in so-called D3, *i.e.* Dull, Dangerous and Dirty situations where a human would be less efficient or at risk. It has quickly appeared that using several drones combined together as a swarm offers many advantages over a single drone [4]: continuous flight, combination of different sensors, security (by lowering the radio footprint of each individual aircraft), etc. The authors have been working on swarming for some 10 years, on both aerial only use cases (*e.g.* CARUS and ASIMUT EDA funded project [3]) but also on combinations of heterogeneous systems, combing aerial and ground vehicles (*e.g* the Green Sword park cleaning system [2]). In recent years, drone swarms have become increasingly popular in the entertainment industry. For instance, companies such as Verity Studios [1] have developed technologies for controlling a swarm of drones (equipped with LED lights) in a variety of live shows under indoor and outdoor locations. However these swarm of drones have been choreographed in advance, or else are being controlled by people with joysticks or teleoperators.

Combining a (possibly) large number of systems together raises a number of issues among which the control of the system has become crucial. This raises a number of issues listed in Figure 1. First, one must be able to give orders to the drone so as to let it know that it has to move to a given location. Second, it must be possible acquire the locate the drone so that the given directions can be applied (moving to a location only makes sense if the notion of location exists in the system). One additional issue in our context is that we are talking about autonomous systems, not about remotely piloted systems (which is the common approach in most if not all of the commercial uses cases that have been developed in both civilian and military context). It means that the drone must have self awareness

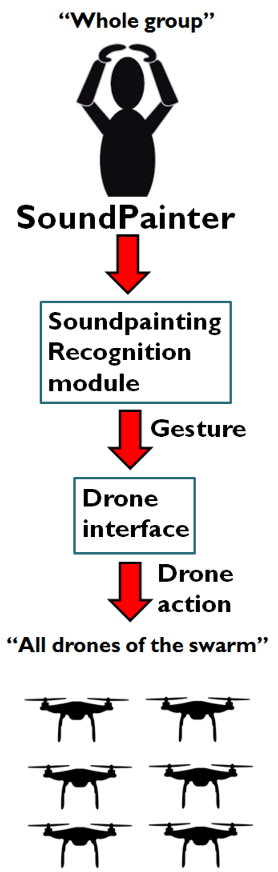

Figure 2: System architecture to control a swarm of drones using Soundpainting language

(autonomous knowledge) of its location. Eventually, being given a large number of drones are used, resilience must be considered [5].

ADDRESSED PROBLEMS, RETEX ON PREVIOUS WORK AND DIRECTIONS TO EXPLORE

GNNS based approaches: retex on our own previous work and associated limitations.

In the previous use cases/research projects described above (CARUS, ASIMUT, Green Sword), we have been running the systems outside buildings, on dedicated (military) fields of experimentation. We thus heavily relied on Global Navigation Satellite System (GNSS). Nevertheless, the hardware we were using add a limited accuracy, and thus we had to leave a significant amount of space between the drones so as to avoid any issue/crash. We still depended on the reception of the GPS signal that we could not guarantee depending on the weather and on possible adverse jamming.

Technologies that make sense to explore.

Most of drone control technologies currently use traditional global GNSS (mainly GPS) systems to provide real-time drone localization. However, such systems, as described above, are not reliable/accurate enough to operate a swarm of drones since they can possibly lead to crashes [6]. In addition, GNSS systems cannot be used in indoor conditions due to signal reception occlusion [12]. Because of these limitations, recent projects have explored different technologies to deal with a swarm of drones that do not rely on some global localization system like satellites. There are for instance motion capture systems [10], ultra-wideband (UWB) signals [8], Simultaneous Localization and Mapping (SLAM) techniques [9] and optical flow technologies [11].

THE USE CASE: AN INDOOR LIVE OPERA PERFORMED BY A SWARM OF DRONES CONTROLLED BY A SOUNDPAINTER

According to artistic director, the objective is to create a form of a live opera in which musicians and drones can collaborate in order to generate together, by improvisation, an original musical composition. A swarm of drones would be used as moving sound sources to produce spatialization of the sound in three dimensions. These drones will generate different movements and sounds according to body gestures performed by a composer, called Soundpainter. In the proposed study case, we explore the use of automatic recognition of SoundPainting gestures for efficiently controlling a swarm of drones.

The Soundpainting is a gestural language, proposed by Walter Thompson [13], consisting of a well-defined grammar for conducting a large ensemble of improvising artists (musicians, actors, dancers and visual artists) without the use of any score. The advantage of Soundpainting is that it already integrates the notion of groups of entities and makes it possible to control one single entity of a set/subset and to control the set as a whole. Indeed, Soundpainting allows a real exchange and an

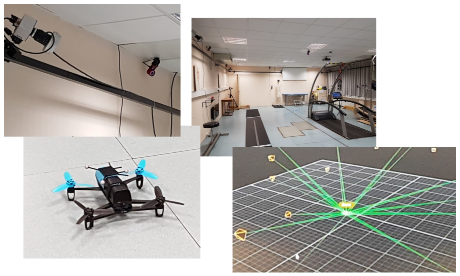

Figure 3: A motion capture system and its output

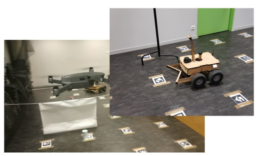

Figure 4: SLAM supplemented with tags

adaptive dialogue between the Soundpainter (here is the pilot) and the group, enabling contextual interpretation by each individual, and generating rich interaction and dialogue. The grammar used in Soundpainting is a set of gestures classified in four subsets: *Who*, *What*, *How* and *When*. A gesture *Who* indicates who is chosen by the Soundpainter. A gesture *What* indicates what Soundpainter wants to be done (e.g., hold a note). A gesture *How* indicates how Soundpainter wants the action to be done (e.g., in the case of sound, loud, fast or high). A gesture *When* indicates when the Soundpainter wants the action to start and/or stop. The expressive power of the Soundpainting language in the context of controlling the movements and the sounds of drones was shown in [7].

OUR APPROACH TO CONTROL (A SWARM OF) DRONES IN AN INDOOR CONTEXT

Research directions for issue 1 : controlling the drones/swarm of drones

According to our study case, the Figure 2 shows the proposed system architecture to control a swarm of drones using Soundpainting language. First, the Soundpainter performs a Who gesture ("Whole Group" here) in front of a gesture recognition software. Second, the recognized gesture is sent to the drone interface that controls the drones. Finally, the swarm reacts to the gesture "Whole Group", then stands ready to react to the next one. In the gesture recognition software, the body movement is grabbed via a non-intrusive motion capture system (e.g., a Kinect sensor). Then a machine learning model would be trained to recognize, in real time, Soundpainting gestures from the 3D joint coordinates extracted from the motion capture sensor. The result is the recognized gesture that is sent to an interface in charge of transforming it into instructions interpretable by drones (ARDrones modified to UDP client). Here is the main problem ; how to locate drones correctly in an indoor environment to compute movements?

Research directions for issue 2 : making the drone aware of its location

Motion capture. Using a motion capture system can be a very efficient approach as far as precision is concerned (see figure 3). Nevertheless, the drones must be equipped with sensors that are detected by cameras that have to be installed all over the flying area. This makes it possible to have a very precise location but the price to pay is in terms of instrumenting the drones, instrumenting the area and calibrating the system before use. Additionally, the number of cameras must be very important so as to avoid obfuscation between the drones.

SLAM. The Simultaneous Location and Mapping is an approach that consists of building a map of the flying area in real time so as to achieve location relative to this reconstruction. It requires to have a camera on the drone and enough computing power to run the SLAM algorithm inside the drone (required because we want to operate in real time) (see figure 4). Additionally SLAM only works properly provided a significant number of POIs (Point Of Interest) can be captured which is

Technology	Accuracy
GPS	6m-10m
Infrared	1m-2m
Wi-Fi	1m-5m
Ultrasound	3cm-1m
RFID	1m-2m
Bluetooth	2m-5m
Zigbee	3m-5m
FM	2m-4m

Table 1: Comparison of the accuracy of the major radio technologies (source [14])

Figure 5: A rehearsal of the opera with drones and musicians directed by a Soundpainter

an issue in some situations and requires a lot of calibration to adapt to a given environment. In case the environment is not adapted (because of bad lighting for instance) the system can be augmented with external tags. We have experimented this approach in our Green Sword use case that consists in cleaning a green park with a swarm of air and ground vehicles and we obtained a correct location, even though not as good as what we had with motion tracking.

UWB. Many Ultra Wide Band or other radio-based approaches have been developed and experimented as shown in table 1. Most of them (if not all) suffer from the variability of their output and from their dependence on the environment. It is thus required to have the radio nodes to remain in place for a very long time so as to acquire a footprint of the location in terms of its "radio behavior" before it can be used to efficiently position a moving target (drone).

Sound based location. Using sound waves instead of radio waves seems to be a good alternative because sound waves are less subject to radio noise, even though it is of course subject to noise (in terms of sound noise).

Research directions for issues 3 and 4: building a self-contained system and making the system resilient

How can a system without external setup locate itself ? Building a self-contained system is probably one of the most challenging issues and it is a key to future applications of drones. This problem is listed here for the sake of completeness, but it is not an issue in our use case (more precisely, should this be impossible we can instrument the area where the show has to take place). Regarding resilience, the reader is referred to [5].

PRELIMINARY RESULTS AND CONCLUSION

The different projects that we have carried out in the recent years and that required precise location of the drones have raised a number of issues in terms of precision, stability, etc. It has basically been impossible to have a location more accurate than a few meters. To develop these use cases we thus had, each time, to setup dedicated approaches that most of the time led to lower our expectations in terms of scenario (making the drones fly far away from each other, forbid some moves, etc.). In the current use case, the Soundpainter directed opera, accuracy is required; there is no way to lower our expectations in terms of freedom of the director. Therefore, we have begun experimenting four directions: firstly, testing new radio based location systems; secondly, adapting the flight path of the drones in the swarm so that we require less accuracy; thirdly, changing/limiting the scenario that can be run by the director; and fourthly, experimenting the sound location.

The goal of this paper is to open a discussion with the community regarding one of the key issues linked to the interaction with an semi-autonomous swarm by gestures: the positioning. Even though technologies have become mature, we shown that it remains issues of indoor and adverse locations and we showed that the problem is four-folds (Figure 1). Our use case, an opera with drones and musicians (see figure 5) directed by a Soundpainter, leads to a real exchange and an adaptive dialogue between the Soundpainter (that could be seen as a pilot) and the swarm, enabling contextual interpretation by each individual, and generating rich interaction and dialogue. This usage requires precise location of the drone and needs an efficient positioning technology.

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