Spatial and frequency characterization of the noise generated by the propellers of Unmanned Aerial Vehicles (UAV) in acoustic localization tasks

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ABSTRACT

In the field of surveillance applications for an Unmanned Aerial Vehicle (UAV), detecting and locating people in low visibility environments is a complex task. In these scenarios, the use of conventional cameras is not feasible, and the use of alternative technologies to the optical ones is needed. The authors carried out previous works to analyse the viability of using an acoustic camera located in the proximity of an UAV to locate people asking for help. This acoustic camera is based on a MEMS microphone array where frequency and spatial filtering techniques, based on a broadband acoustic beamformer, are applied.

The work presented in this paper shows the characterization of the noise generated by the propellers of a UAV, in order to discriminate this noise from the cries for help in the acoustic localization tasks carried out by the acoustic camera, For the tested scenario, the MEMS microphone array is onboard the UAV, mounted on a Gimbal that stabilizes the array position.

1. INTRODUCTION

Using flying Unmanned Aerial Vehicles (UAV) to locate people crying for help is a tendency. It is usual that the navigation system of an UAV used to locate people uses thermal cameras and RGB Depth cameras. The problem with these systems is that they not show a good behaviour if the environment visibility is reduced, like on a fire. Within this framework, these RGB cameras do not show a good behaviour, and the performance of the thermal ones is very limited [1]. So, under these circumstances, an idea arose to analyse if it would be feasible to include an acoustic array on a drone, to detect people in danger from their cries for help.

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In a previous paper [2], based in this idea, the authors study the feasibility of discriminating UAV propellers noise from distress signals to locate people in danger, using an array of MEMS microphones. Some tests were carried out in order to locate the angles of arrival of different sound sources, including whistles and calls for help, in indoor environments. In the tests carried out in this paper, the acoustic array was not integrated on the drone, due to its high dimensions [3]. The limitation of those tests was that the array was not integrated onto the drone. Instead of that, it was placed near it, but a certain distance. The methodology presented in that paper showed that the system was able to estimate the angles of arrival of direct and reflected signals in an indoor space, if the drone noise levels were low or medium.

Smart acoustic systems are based on arrays. An array is an arranged set of identical sensors, fed in a specific manner [4]. By using beamforming techniques [5], the mainlobe of the array beampattern can be electronically steered to different spatial positions, allowing the array to discriminate acoustic sources on the basis of their position. Particularly, microphone arrays are used in applications such as speech processing, echo cancellation, sound sources separation and localization [6], or to detect and track the position of drones [7-8]. The application of MEMS (Micro-Electro-Mechanical System) technology to acoustic sensors has allowed the development of high-quality microphones with high SNR (Signal to Noise Ratio), low power consumption and high sensitivity [9-10]. These characteristics reduce costs and the space occupied by the system.

In order to validate that the methodology published in [2] can work with any kind of drone, even if the array is integrated on it, a spatial and frequency characterization of the noise generated by the propellers of the new drone acquired by the authors has been carried out and shown in this paper. In this study, the propellers noise has been capture by the own array that is embedded on the drone whose noise is under analysis. This spatial and frequency characterization will be used on future tests for the validation of the above mentioned methodology [2] with different drones.

Section 2 introduces the description of the system used in this study, showing the drone and the hardware platforms that compose the acoustic system. Section 3 and 4 presents, respectively, the spatial and frequency characterization of the noise generated by the drone propellers. Finally, Section 5 contains the conclusions that authors have drawn on the basis of the obtained results.

2. HARDWARE SETUP

The work shown in this paper is focused on the spatial and frequency characterization of the noise generated by the propellers of the new drone acquired for the authors. This noise was captured by an array of MEMS microphones that is integrated on the own drone.

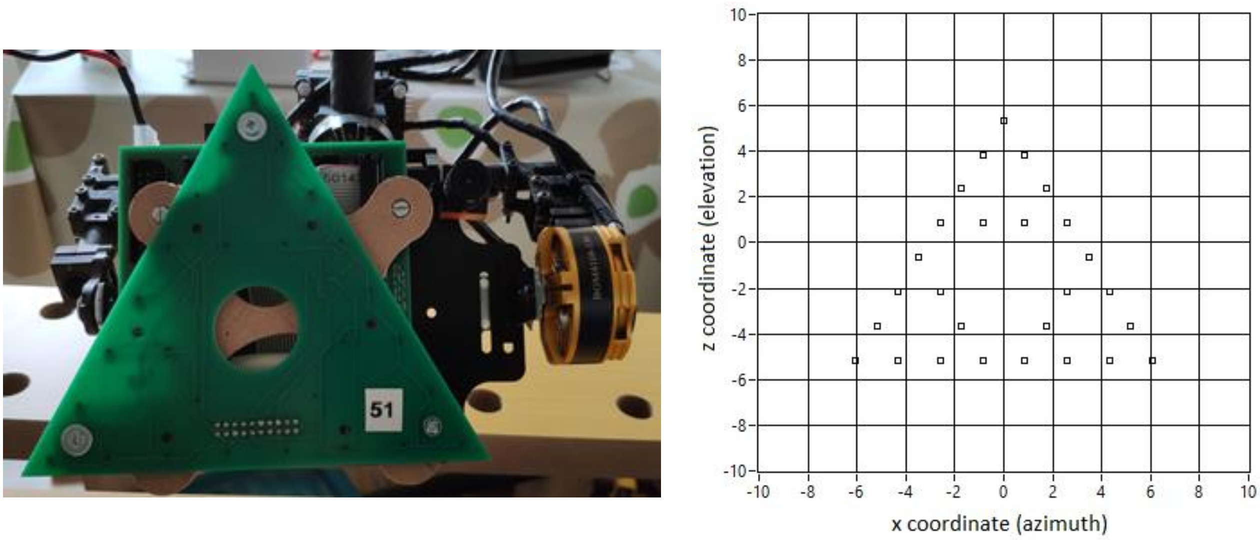
2.1. Drone

As shown in Figure 1, the drone that has been employed in the tests associated to this work is the DronTecnic DT6P model. This drone has six TAROT 4108-380KV electrical rotors, each one with a propeller with a diameter of 330mm. A Pixhawk 2.1 Edison and a Here GNSS flight controller power the drone. The FRSKY Taranis QX7 monitoring system is based on a wireless multifunction device with 16 2.4GHz-channels. The telemetry and the remote management system of the drone is a Datalink Modem 3DR of 433MHz. It has a Boscam 5.8GHz video receptor and a MEMS microphone array, this last on a 3-axis HakRC gimbal. Its weight, without the camera, the MEMS array nor the battery is 2.3 kilograms, and its maximum take-off weight is 4.5 kilograms.

Figure 1: DT6P Drontecnic drone

2.2. Acoustic system based on a MEMS array and a sbRIO platform

The acoustic images acquisition system used in this paper is based on the Planar Array of MEMS microphones shown in Figure 2a. This array, developed by the authors, is an array with 27 MEMS microphones distributed in an equilateral triangle of 135mm side, whose positions can be observed in Figure 2b.



(a) (b)

Figure 2: MEMS array board (a) and MEMS positions

This array was designed to work in an acoustic frequency range between 4 and 16kHz. Therefore, the 17.32mm spacing corresponds to $\lambda/2$ for the 10kHz central frequency. This spacing allows a good resolution for low frequencies, and also avoids grating lobes for high frequencies in the angular exploration zone of interest.

For the implementation of this array, SPH0641LU4H-1MP34DT01 digital MEMS microphones of STMicroelectronics Knowles [11] —with PDM interface—were chosen, with the following features: low-power, omnidirectional response, 64.3dB SNR, high sensitivity (-26dBFS) and a nearly flat frequency response (± 1dB in the range of 100Hz to 10kHz, and between 2dB and 14dB in the range of 10kHz and 80kHz).

A sbRIO 9607 platform [12] is the base unit for this system. The sbRIO is based on an ARM processor and a Zynq-7020 FPGA. This platform is controlled through a CompactRIO Single-Board and has a CPU Dual-Core, which works at 667MHz, a 512MB DRAM, and 96 IO ports. This platform belongs to the Reconfigurable Input-Output (RIO) family of devices from National Instruments, which is oriented to sensors with nonstandard acquisition procedures. The embedded processor included in sbRIO can run all software algorithms to generate acoustic images, and so it is used as a standalone array module, connected to a MEMS array board, and controlled from a PC connected using a Wi-Fi interface. Figure 3 shows the acoustic system hardware setup.

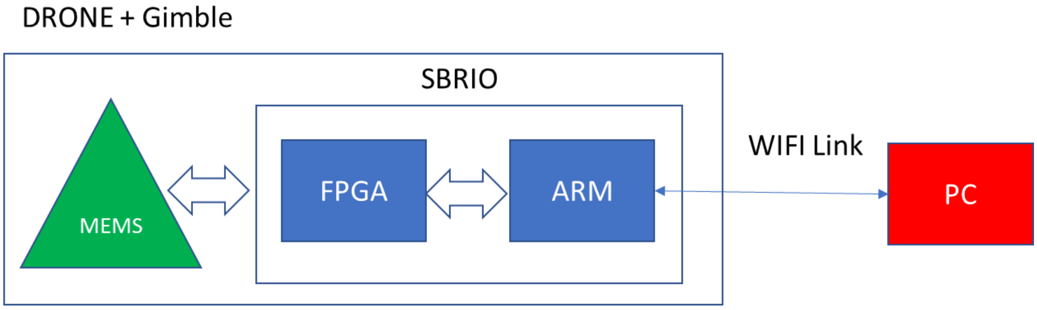


Figure 3: Acoustic system hardware setup

As explained in [3], the algorithms implemented in the system, using LabVIEW, can be divided into three blocks:

- MEMS acquisition: Each MEMS microphone acquire an acoustic signal, formed by a mixture of desired signal, propellers noise and background noise.
- Signal processing: the data from the MEMS microphones are preprocessed, obtaining 27 independent signals. After that, each signal is filtered in order to eliminate the noise from the drone propellers or other sources like environmental noise.
- Direction of Arrival (DOA) assessment: The angle of arrival of the acoustic signal is estimated. An acoustic image is obtained by using wideband beamforming [4-6]. This algorithm can be considered as a spatial filter to estimate, in this case, the sound pressure level (SPL) of for a given direction of arrival.

3. SPATIAL CHARACTERIZATION

As MEMS microphones capture acoustic signals which are composed by a mixture of desired/help signal and noise, a characterization of part of this noise has been carried out, in order to facilitate the discrimination of the DOA of the desired/help signal. Background or environmental noise is usually random, so its characterization is not feasible. The only noise that we are able to characterize is the one generated by the propellers of the drone. The propellers are the noisiest part of an operative drone.

So, the first step in this characterization was focused on the analysis of the spatial position of the noise, due to the relative position between the array and the drone propellers. Figure 4 shows a diagram of the plan and the profile of the drone, where the positions of the propellers, as well as their relative position to the array, can be observed. Figure 4a shows that the centre of each propeller, with a radius of 230mm, is placed at the end of one of the six 480mm-arms of the drone. Figure 4b shows that the MEMS array is placed in the centre of the drone, at a distance of 300mm below the plane containing the propellers.

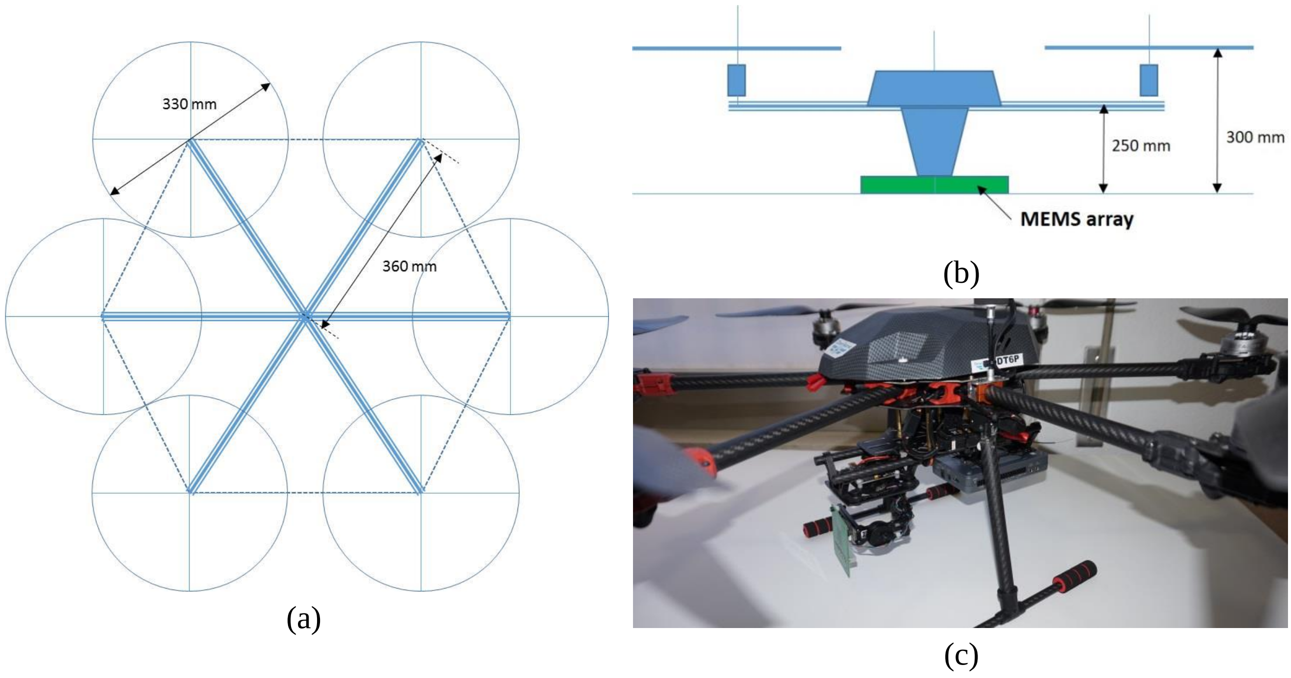


Figure 4: Drone diagram. (a) Plan. (b) Profile. (c) System.

If it is considered that the noise of the propellers is generated by their edges, the theoretical position of this noise received by the MEMS array is observed in Figure 5. In this Figure 5, the position of the centre of each propeller is indicated with a red cross, and it can be observed the trajectory of the edge of each propeller while they are rotating. It can be observed that although the trajectory of the edges of the propellers is circular, in angular coordinates, since the plane of the helix is not in the centre of coordinate reference system, a distortion is produced.

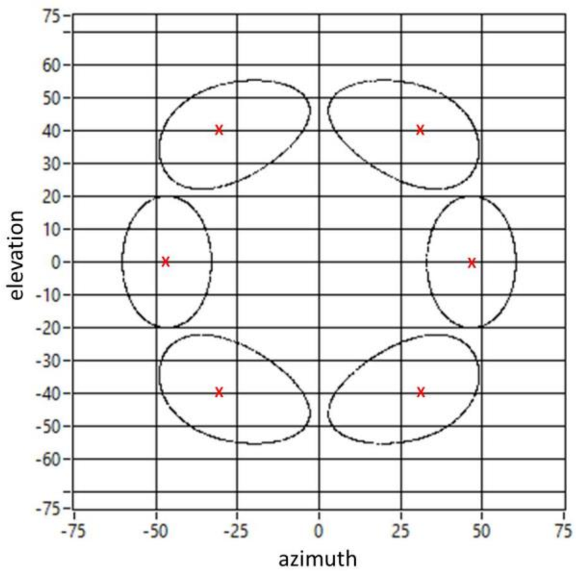
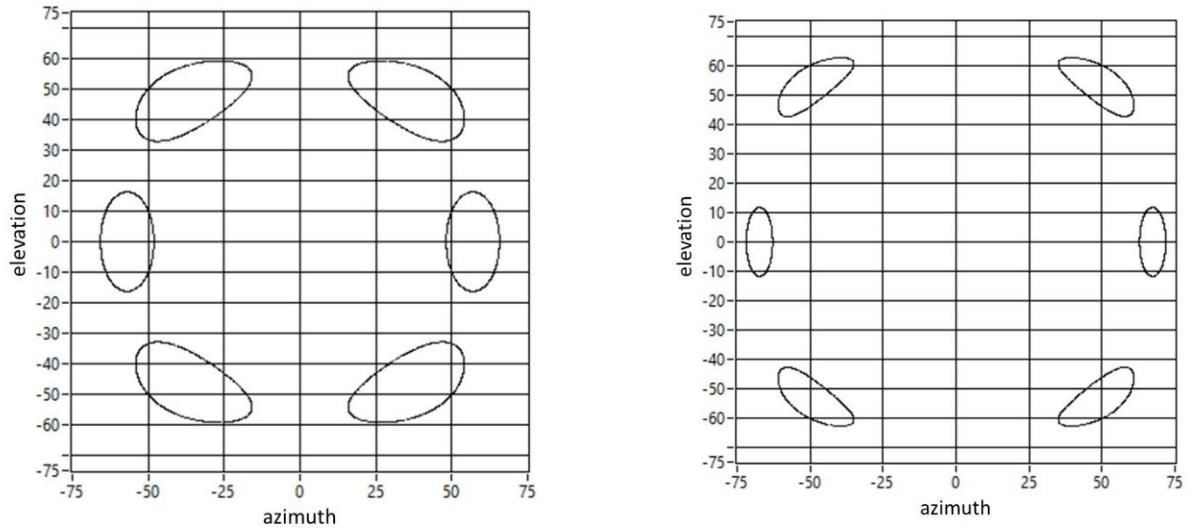


Figure 5: Position of the noise generated by the edge of the propellers

It is interesting to point that the noise arrives to the MEMS array through its back side, and that there isn't noise in the area where the array is placed, that is at the centre of the array. The current system geometry provides a 30º azimuth and elevation free noise area. Depending on the width of the mainbeam of the array, it would be possible that this free noise area should be bigger, that is it would be necessary to separate the array from the noise of the propellers.

In this case, one possible solution could be the increment of the length of the arms where the rotors are placed. As it can be observed in Figure 6, if this length increases, the propellers noise and the array would be further apart.



(a) (b)

Figure 6: Propellers noise positions with an arm length of 500mm (a) and 750mm (b).

It might be thought that another solution to this problem might be to separate the array vertically from the drone, as shown in Figure 7. It is true that if the array is separated vertically, the noise level received by the MEMS microphones of the array will decrease, but this solution is not feasible.

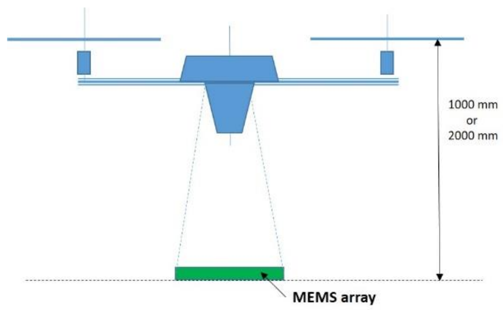
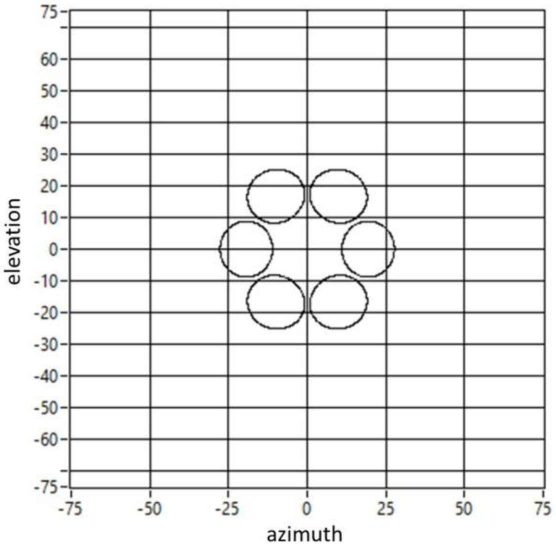
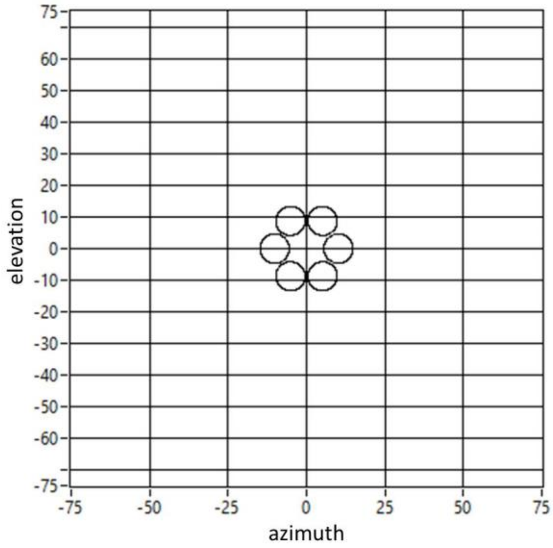


Figure 7: Increment of the vertical distance between propellers and array.

In Figures 8a and 8b it can be observed that if the distance between the drone and the propellers increases, the angular sector where the propellers move will be closer to the coordinate origin and therefore within the surveillance zone of the array. It can also be observed that if the distance between the drone and the propellers increases the distortion on the circular shape on the trajectory of the edges of the propellers, shown in Figures 5 and 6 decreases.



(a)



(b)

Figure 8: Propellers noise positions with a propellers-array distance of:
(a) 1000mm, (b) 2000mm.

4. FREQUENCY CHARACTERIZATION

The next step in the propellers noise characterization was focused on the analysis of the frequency characteristics of this noise. As it was mentioned in the previous section, the acoustic signals that were analysed, that is the propellers noise, were captured by the own MEMS array that is embedded on the drone.

For this characterization, two operational situations, or states, of the drone have been defined.

- State 1: Drone on a stationary situation (hovering).
- State 2: Drone describing slow movements.

These drone states are the same states in which the methodology defined in [2] works.

The frequency information of the noise generated in each of these operational situations has been analysed. For both states, 100 captures of the specific propellers noise have been carried out, and the mean of the frequency spectrums for each state has been assessed, in order to analyse the frequency information of each state-noise. It is feasible to work with mean values of the frequency spectrum because the frequency characteristics of the noise generated by the propellers remain stable over time, as it can be observed in Figure 9, where an example of state 1 noise is shown.

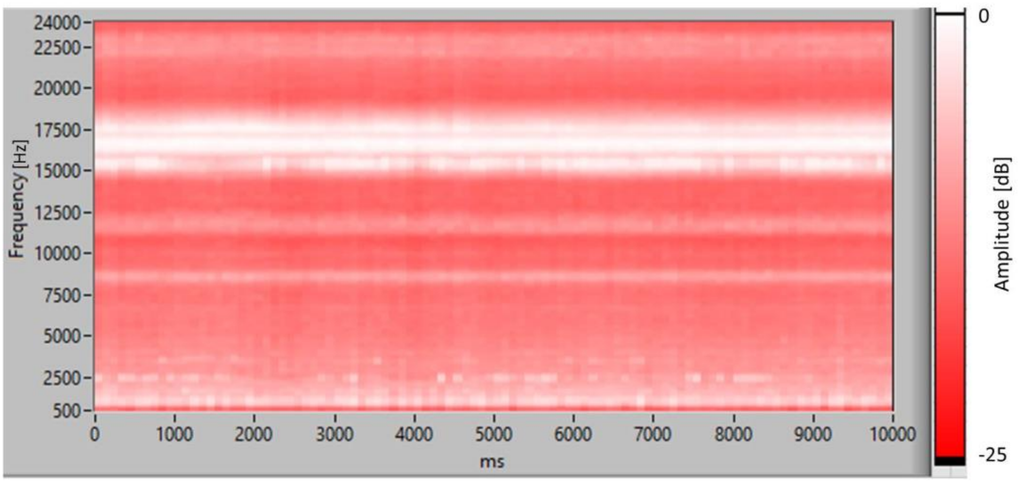


Figure 9: Stable frequency characteristics of the propellers noise over time

The frequency characteristics of the different operational modes of the drone have been analyse:

- State 1:

The frequency spectrum of the noise generated by the propellers of the drone, when the rotors run at their minimum speed, at a stationary situation, is shown in Figure 10. In this spectrum it can be observed that all its frequencies components are higher than 2.5dB in all cases.

In this state, the highest noise level is around 16kHz, with a wide range of frequency components between 14kHz and 18kHz, with high amplitude values, up to 18dB. This spectrum also shows three peak values around 8kHz, 11kHz and 22kHz, with lower amplitude values (8.5-10dB) These noisy frequency components are not problematic because they can be eliminated with a low pass filter, and they do not interfere with the desired/help signals (whistles and voice, cries, signals), whose frequency spectrums are distributed on frequencies below 8kHz. The problem could be the frequency components of the noise distributed at frequencies under 2kHz, with values higher than 10dB, that are going to be mixed with the ones of the desired/help signals, and they are going to interfere in the capture, making more difficult the discrimination between noise and desired signal. In this case, the desired signals should have an amplitude higher than 15-20dB, in order to be discriminated from the noise.

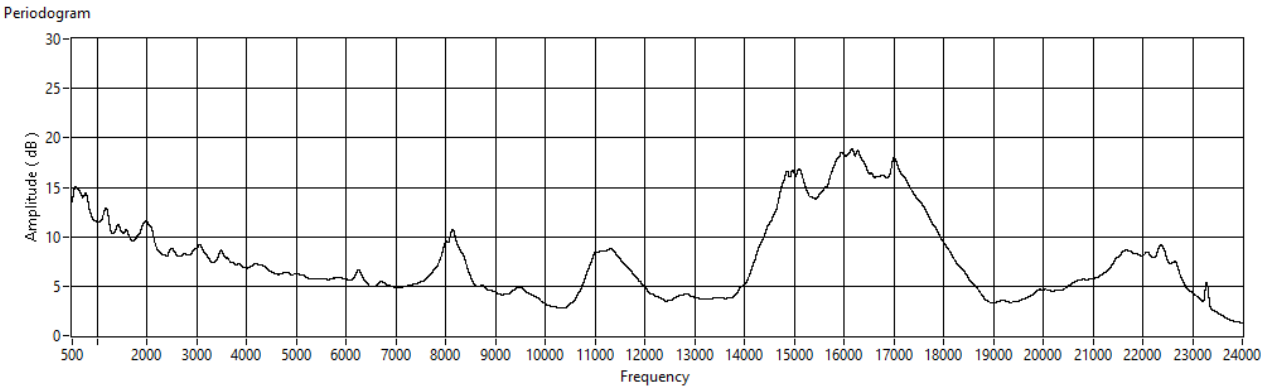


Figure 10: Propellers noise frequency spectrum of state 1

- State 2:

The frequency spectrum of the noise generated by the propellers of the drone, when the rotors are running at variable speed, is shown in Figure 11. In this spectrum, it can be observed that in this operational situation, the frequency components are similar to the ones in Figure 10, that is, in state 1, but with higher amplitude values for all the frequencies of the spectrum. In this case, the noise level is higher than 12.5dB in all cases.

In this state 2, the highest noise level is not around 16kHz, where there is again a maximum (20dB), but the maximum noise level is at around 600Hz. There are also little maxima around 8kHz, 11kHz and 22kHz, as in the previous state 1, but their amplitude values are not much higher than the minimum value of 12.5dB. Again, these high frequency components are not problematic because they can be eliminated with a low pass filter, but the problem with the noisy frequencies components under 2-3kHz worsen, with amplitude values higher than 17.5dB, and up to 23dB. In this case, the discrimination between noise and desired signals is going to be more difficult. In this case, the desired signals should have an amplitude higher than 22-25dB, in order to be discriminated from the noise.

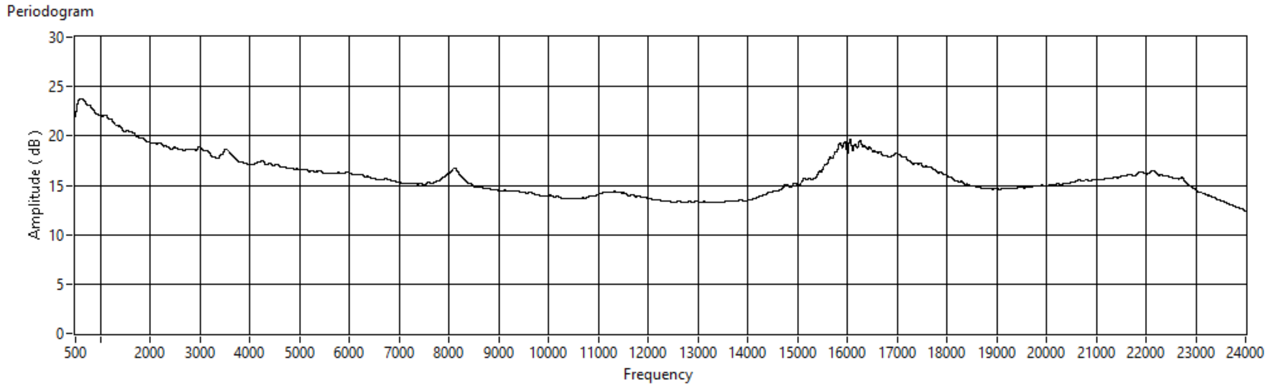


Figure 11: Propellers noise frequency spectrum of state 2

5. CONCLUSIONS

From the point of view of the spatial analysis, it has been observed that due to the location of the propellers noise, other sounds that are located under the drone at angles higher than 30º could be detected. This noise might be mainly due to the propellers behind the drone, which the radiation pattern of the array will appear as noise sources in positions with inverted angles. But even though the noise is generated behind the array, it is radiated forward and eventually detected by the array.

From the frequency analysis point of view, it can be indicated that the frequency band where the drone propellers generate less noise is the band between 3kHz and 8kHz. Taking into account that whistles normally emit tones in this frequency band between 3kHz and 8kHz, and taking care of controlling that the drone flies in stable mode so that the engines do not rotate at high speed, the noise of the propellers would be controlled, and it would be possible to detect whistles as distress signals. The problem could arise with voice signals, which cover a wider frequency range, below 3kHz. It would be necessary to make real tests of the methodology using the new drone, which has incorporated array, with different types of distress signals (whistles and voice, as cries for help) to analyse if the detection methodology is able to detect the position of these distress signals.

6. ACKNOWLEDGEMENTS

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