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DRONE LOCALIZATION USING DIRECTIVITY OUTPUTS OF A NOISE MONITORING SYSTEM

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The use of acoustics for drone localisation has gained more interest in recent years. Traditionally, acoustic localisation is done using microphone arrays. The data is processed with methods such as a time-difference-of-arrival approach or beamforming. It has however not been investigated yet if alternative noise monitoring systems can be used for this purpose. The aim of this research is therefore to investigate if noise monitoring systems which output noise directivity can be used for drone localisation. Four SV200A noise monitoring systems were used during a real-life experiment. These systems output the directivity in the XY-plane from 0° to 360° and in the Z-plane from 0° to 180° in bins with a width of 11.25°. During the experiment, a DJI Phantom quadcopter flew a variety of manoeuvres. For performance evaluation, two flight patterns are distinguished: horizontal and vertical flight. Initial results showed limited performance. In the XY-plane, the percentage of time where the correct bin was estimated varied between 20% to 49% depending on the manoeuvre and microphone, whereas in the Z-plane this was only 0.3% to 14%. However, when including the angular bins adjacent to the correct bin, the performance increased significantly. In the XY-plane, the percentages increased to 63% to 98% and in the Z-plane to 29% to 49%. A reason for this increase can be that the GPS receiver of the drone has limited accuracy, which leads to a mismatch between the true flown position and the logged position. Furthermore, due to an offset in internal clocks of the drone and microphones, some microphone estimations were slightly ahead or behind the actual drone movement. In conclusion, these results show that the noise monitoring systems can estimate the location of the drone if some margin in the estimation is taken into account.
Keywords: Sound source localisation; Noise monitoring systems; Drones

1. Introduction

In the recent years, drone localisation using acoustic sensors has gained more interest. Single microphones or multiple microphones in an array are spread over an area which must be protected against intruding drones. These microphones measure pressure fluctuations over time, which are saved using a data acquisition system. This data is send to another device, such as a computer, where the measured data is processed using a time-difference-of-arrival approach [1–3] or beamforming [4–10].

To make this algorithm work, a system of multiple devices with many data transfers is required. This takes time and requires state-of-the-art hardware to run real-time. To avoid this complex process, it is desired to test a sensor system which can analyse measured data and output an estimation of the drone location directly. The traditional microphones used in previous studies cannot do this. Therefore, alternative noise monitoring systems can serve as a solution. Such systems analyse measured data in a fast and efficient way. They do not output raw pressure measurements, but for example the directivity of the perceived noise. This information can be used to determine the location of the dominant sound source.

To the knowledge of the authors, it has not been investigated yet if drones can be detected directly using the directivity of such a monitoring system. The aim of this research is therefore to answer the following research question: can a noise monitoring system which provides the noise directivity be used to localise a drone? To answer this question, real-world measurement data of four Svantek SV200A noise monitoring systems are used. During the measurements, a DJI Phantom quadcopter was used.

The remaining of this contribution is ordered as follows. To start, details about the measurement will be provided in section 2. After that, the results and discussion are presented in section 3. To finish the contribution, the conclusion is stated in section 4.

2. Measurement Setup

In January 2021, a measurement campaign was organised on an aeromodelling airfield in Salobrena, Granada, Spain. During this campaign, four SV200A noise monitoring systems were used. These systems were numbered and located as shown in Figure 1. The monitoring systems are made by Svantek, a manufacturer of noise and vibration monitoring instrumentations [11]. Each monitoring system consists of four MEMS microphones and the source direction is determined using the phase shift of the incoming signals between these microphones. The direction of the noise is expressed in two planes: the horizontal XY-plane and the vertical Z-plane. In the XY-plane, the direction is given with respect to the north clockwise ranging from 0 to 359°. In the Z-plane, the direction is given from 0 to 180°, where 0° is pointing upwards and 180° pointing downwards. The direction is divided into bins of 11.25°. Per bin, an energy estimate is given expressed as percentage of the total energy in all directions.

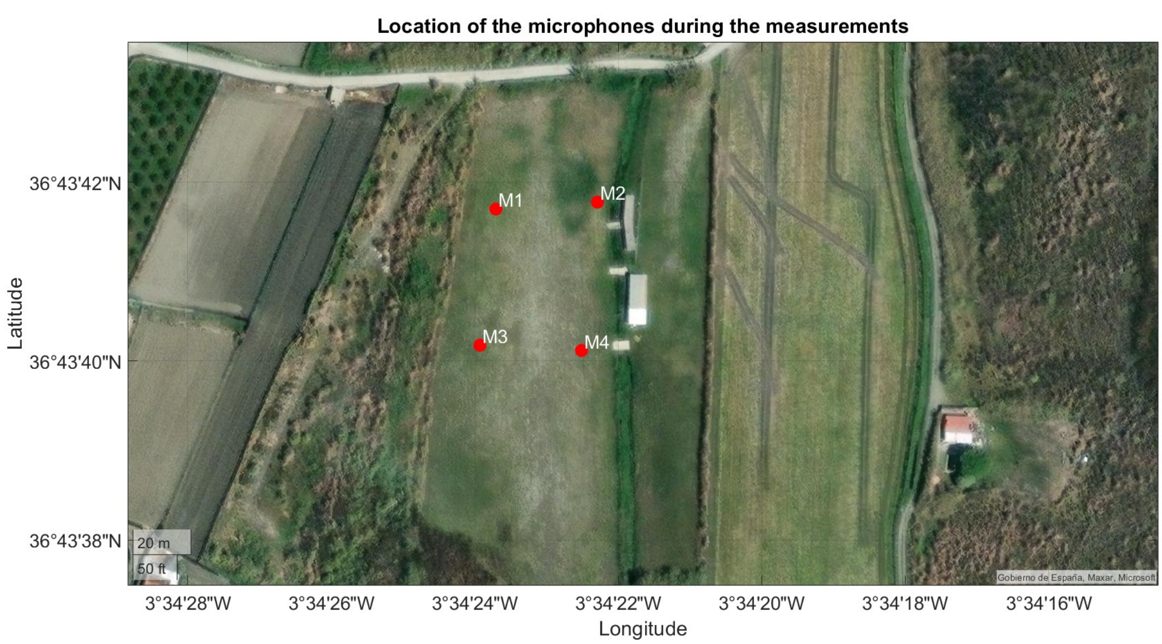

Figure 1: Microphone positions and numbering

The location of the drone is estimated for each monitoring system individually. To do so, it is assumed that the loudest source in the vicinity is the drone. With this assumption, the direction of the drone can be determined directly from the output of the systems. The direction bin with the highest energy is taken as the location of the drone with respect to this system. This is determined for both the XY- and Z-direction.

During the flight test, different manoeuvres were flown. Two vertical flights were performed, where the drone started on the ground, lifted-off to an altitude of 60 meter and landed on the ground again. Furthermore, different horizontal flights were performed. During these flights, the drone flew at a constant altitude of either 15 or 30 meter. The drone flew from either the north side of the microphones to the south side and back, or vice versa. This was done at different locations with respect to the microphones.

For the assessment of the performance of the monitoring systems, the horizontal and vertical flights are separated. This is done because the results showed that different performances were achieved for the different manoeuvres and separating them provides more insight into the limitations of the monitoring systems.

3. Results and Discussion

The performance of the horizontal and vertical flights is determined by calculating the percentage of time in which the true location of the drone falls within the direction bin which has the highest energy. However, during the processing of the data, it was noticed that the true location of the drone sometimes only falls slightly outside the estimated bin. To confirm that this is true, the percentage of time in which the true location falls within the correct bin or in one of the adjacent bins is calculated as well. The percentages are summarised in Table 1 and Table 2 for the XY-direction and Z-direction respectively.

Table 1: Percentage of total time in which the prediction is in the correct bin and in which the prediction is in the correct and adjacent bin for the XY-direction

	Vertical		Horizontal	
Microphone	Correct bin	Correct bin ± 1	Correct bin	Correct bin ± 1
M1	44.9%	97.2%	38.0%	65.4%
M2	20.7%	92.1%	31.3%	63.2%
M3	42.6%	93.4%	43.2%	86.5%
M4	48.8%	97.8%	40.6%	86.5%

Table 2: Percentage of total time in which the prediction is in the correct bin and in which the prediction is in the correct and adjacent bin for the Z-direction

	Vertical		Horizontal	
Microphone	Correct bin	Correct bin ± 1	Correct bin	Correct bin ± 1
M1	7.5%	29.4%	0.9%	32.0%
M2	9.3%	37.4%	2.7%	48.9%
M3	8.9%	29.8%	1.6%	32.0%
M4	14.2%	28.7%	0.30%	37.4%

There are two observations which can be made based on these results. The first observation is that it is clear for all microphones, manoeuvres and for both direction that the performance increases significantly when the adjacent bins are considered as well. This confirms the hypothesis mentioned before that sometimes the estimate only falls slightly outside the correct bin. A possible explanation for this discrepancy between the true location and predicted location is that GPS systems in drones are not perfect and generally have a limited accuracy of a few meters. This can result in a small mismatch between the true flown position and the logged position and consequently a similarly small mismatch between the logged position and the estimated position. Therefore, including the adjacent bin resolves this issue.

The second observation is that the estimations in the Z-direction are significantly worse than the estimations in the XY-direction. One reason for this is the limited capability of the drone to correctly estimate the altitude. The drone estimates the altitude with respect to the mean sea level, which is not the same as the altitude compared to the ground at the measurement site. This can be accounted for by subtracting a reference altitude when the drone is standing on the ground from all altitude measurements. However, this reference altitude varied during the measurements, due to e.g. irregularities on the ground. Therefore, only an average reference altitude could be computed. Apart from the previously mentioned limited accuracy of a GPS system, this incorrect reference altitude introduces another uncertainty in the GPS track in the Z-direction. This results in an even more inaccurate GPS track in the Z-direction compared to the GPS track in XY-direction. However, this is not the only reason. The systems do have a worse localisation performance in the Z-direction. This is confirmed by looking at Table 3.

Table 3: Percentage of total time in which the prediction is in the correct bin and in which the prediction is in the correct and adjacent bin for the horizontal flights per altitude

	15 meter				30 meter			
	XY-Plane		Z-Plane		XY-Plane		Z-Plane	
Microphone	Correct bin	Correct bin $\pm$ 1	Correct bin	Correct bin $\pm$ 1	Correct bin	Correct bin $\pm$ 1	Correct bin	Correct bin $\pm$ 1
M1	34.7%	63.5%	0.3%	49.8%	42.3%	67.7%	1.6%	9.5%
M2	29.7%	58.8%	4.8%	67.0%	33.4%	68.8%	0.0%	26.0%
M3	41.3%	88.6%	1.2%	42.4%	45.5%	83.9%	2.1%	18.7%
M4	42.1%	88.8%	0.3%	58.5%	38.8%	83.5%	0.3%	10.6%

In this table, the horizontal flights at 15 and at 30 meter are compared for both the XY-direction and Z-direction. In the XY-direction, some differences of maximum 10 percentage points are found, which can be attributed to changes in horizontal position of the drone with respect to the microphones and influence of noise. However, in the Z-direction the differences are more pronounced, in particular for the correct bin $\pm$ 1. All microphones show a significant decreasing percentage when the altitude is increased. This means that the localisation capability of these systems in the Z-direction is limited.

This finding is even more pronounced by plotting the true and estimated location of the drone together. For this, Figures 2 and 3 are included. They show results in both XY- and Z-direction for a horizontal and vertical flight respectively. The figures show the true GPS location compared to a given microphone in red and the upper and lower boundary of the estimated bin of the given microphone in black. Furthermore, a map with the flight path in red is shown as well.

Figure 3, which shows the results for the vertical flight, clearly supports the observation that the estimation in the Z-direction is not accurate when the altitude is increased. Especially the third and fourth system fail to estimate the location correctly, which is partly due to the fact that the drone is manoeuvring closer to system 1 and 2 than to system 3 and 4.

Beside this observation, another interesting behaviour appears in Figure 2. It can be seen that especially for the first two systems, the GPS track and microphone estimations are off in time. The estimates lag the true location of the drone. One reason why this happens is that there might be a clock difference

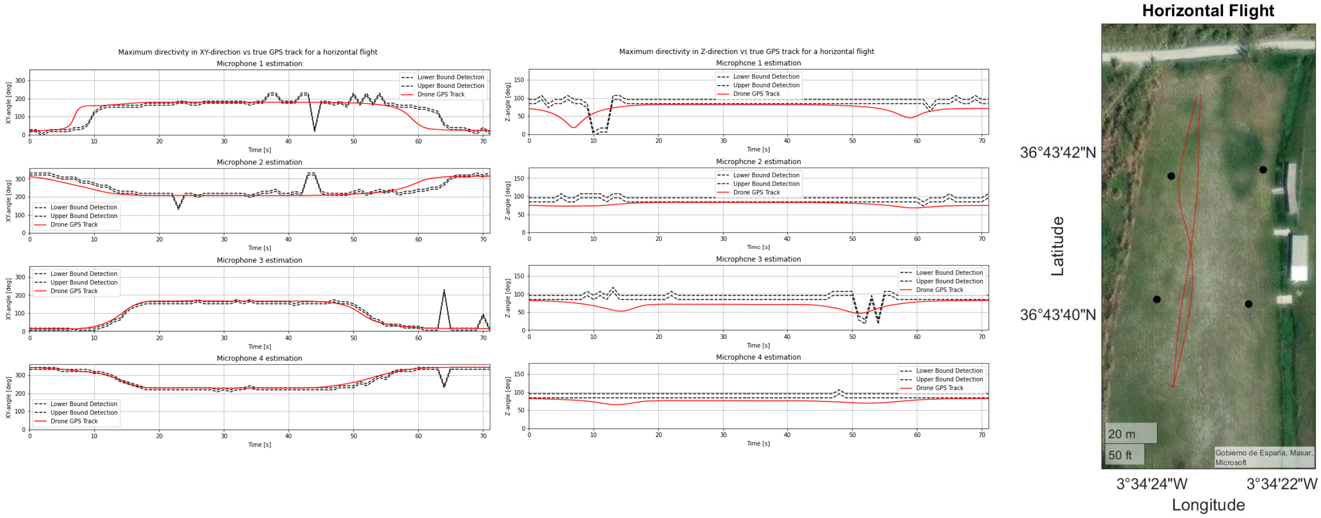

Figure 2: Localisation results for a horizontal flight at an altitude of 15 meter

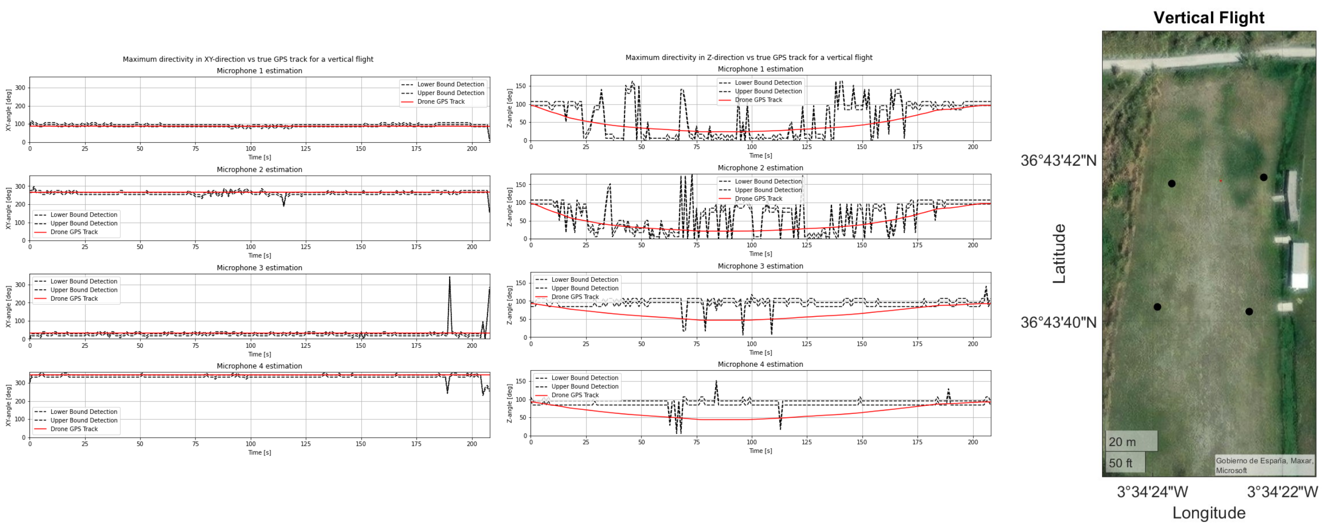

Figure 3: Localisation results for a vertical flight

between the drone and that system. All four systems and the drone log their data relative to an internal clock. However, these clocks do not necessarily run in sync with each other. There can be a bias between the GPS clock and a system's clock due to which the GPS track and the estimation do not align.

It should be noted that both reasons why the estimations are incorrect only affect offline post-processing. Both issue do not rise during real-time usage of these systems. It is therefore expected that the performance would be better in real life compared to the post-processed results presented here, which makes these system suitable for the application of drone localisation.

4. Conclusion

The research presented in this contribution aims at answering the question whether a noise monitoring system which provides noise directivity in XY- and Z-direction can be used for drone localisation. The results initially showed that the localisation performance was limited. However, this can partly be attributed to uncertainties in the GPS track. The GPS system of the drone is not perfectly accurate and especially in the altitude measurements there are deficiencies. Apart from this, during post-processing a mismatch in internal clock between monitoring systems and the drone GPS system was encountered, which also lowers performance. Due to this, for many manoeuvres the GPS track was only slightly outside the estimated direction bin of the microphone systems. Therefore the adjacent bin was included as well, which improved performance significantly. Furthermore, it should be noted that both issues only arise due to post-processing the data. When used in real-time, these issues would not be presented. Even though part of the limited performance can be attributed to post-processing issues, it should be noted that performance in the Z-direction remains limited, with a varying performance for different manoeuvres and monitoring systems from 29% to 49%. In the XY-direction the performance is much better, varying between 63% and 98%. It can thus be concluded that, especially in the XY-direction, the directivity outputs of noise monitoring systems can be used for drone localisation.

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