Analysis of a maxima position estimator on acoustic images of a fan matrix for failure detection

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Summary

In a previous research work carried out by the authors, the acoustic images of a matrix of fans were used to detect operation failures on some fans. Promising results showed that geometric parameters of these acoustic images, obtained using a 16x16 planar array of MEMS microphones, could be used to detect if the fans are or are not working properly. Since the noise that each fan of the matrix shows a spectrum with several harmonics, it is necessary to decide in which frequency, or frequencies, the acoustic images analysis must be centered. This frequency analysis will obtain the best information to detect operation failures on the fan matrix. On the basis of these results, this work analyzes the behavior of an estimator of the maxima positions of the acoustic images, in order to use this information subsequently in a failure detection system for the fan matrix. This estimator has been analyzed considering different scenarios: only one of the fans of the matrix is running, and the opposite scenario, that is, all the fans of the matrix, except one of them, are running. Both scenarios show that the performance of the estimator is different if high frequencies or low frequencies are considered. These analyses show that the use of this estimator is reliable when only one of the fans is running. In the opposite scenario, the estimator is reliable only if low frequencies are taken into account.

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1. Introduction

In recent years, techniques for obtaining acoustic images have developed greatly and rapidly. At the present, acoustic images are associated with a wide variety of applications, such as non-destructive testing of materials, medical imaging, underwater imaging, SONAR (Sound Navigation And Ranging), geophysical exploration, etc. [1]. Acoustical imaging techniques are based on the RADAR (RAdio Detection And Ranging) principles, forming an image of an object from reflected sound waves instead of radio waves, representing a simple low cost alternative. This work is related with one of these applications of acoustical imaging, obtaining acoustic images of machinery to be used in condition monitoring and fault detection tasks.

The detection of a fault consists of the determination of the existence either of a failure in structural components or of an abnormal behavior of a system [2]. Condition monitoring is the process of monitoring a parameter of condition in machinery (vibration, temperature etc.), in order to identify a significant change which is indicative of a developing fault. The use of condition monitoring allows maintenance to be scheduled, or other actions to be taken to prevent consequential damages and avoid its consequences, as a major failure [3].

The classic approach for monitoring of machinery is based on making periodically vibration measurements of the equipment, and then comparing them to known healthy/damaged data to assess the health status of the machine [4]. Sometimes, vibrational measurements need a sensor mounted on the machine, as accelerometers, and this presence can imply disturbances on the machine response and performance. As vibrational responses are related to acoustic emissions, one possible solution to this problem is the analysis of the related acoustic responses, instead of the vibrational ones. Acoustic-based diagnosis with non-contact measurement is a good option, as sound field contains abundant information related to fault patterns [5].

Arrays of MEMS microphones [6] are specially designed for acoustical imaging. An array is an arranged set of identical sensors, fed in a specific manner. The beampattern of the array can be controlled by modifying the geometry of the array (linear, planar...), the sensor spacing and the beampattern, the amplitude and phase excitation of each sensor [7]. By using beamforming techniques [8], the array beampattern can be electronically steered to different spatial positions, allowing spatial filtering, i.e. the discrimination of acoustic sources on the basis of their position.

The authors of this paper have experience in the design and development of acoustic arrays. This work is based on the use of a planar array of 8x8 MEMS microphones [9] to acquire and process acoustic images of a fan matrix [10-11], in order to detect if it is working properly. A fan matrix, fan array or fan wall is a system formed by several fans located on a surface, working together in order to improve the performance of one alone large fan with lower power consumption. Any type of application that requires specific temperature conditions is a candidate for a fan matrix.

An analysis of the systems which uses fans matrices reveals that they have not a subsystem to control if any of the fans that compose the matrix is down or is not working properly. It would be very useful to detect these kinds of situations. The aim of the authors is to develop a novel fault diagnosis method to detect faulty behaviors on the fans included in a matrix. This method will be based on the analysis and classification of acoustic images of the fan matrix, obtained via an array of MEMS microphones, using machine learning techniques.

On the first step of this research [10], a previous analysis of the viability of using an array of 8x8 MEMS microphones to obtain acoustic images of fan matrices was carried out, obtaining positive results. In the subsequent research work [11] carried out by the authors, these obtained acoustic images of a matrix of fans were used to detect operation failures on some fans. Promising results showed that geometric parameters of these acoustic images, obtained using the planar array of MEMS microphones, could be used to detect if the fans are or are not working properly.

On the basis of these results, this work analyzes the behavior of an estimator of the maxima positions of the acoustic images as the geometric parameter to be used later by the machine learning algorithms which detect operation failures on the fans of the matrix.

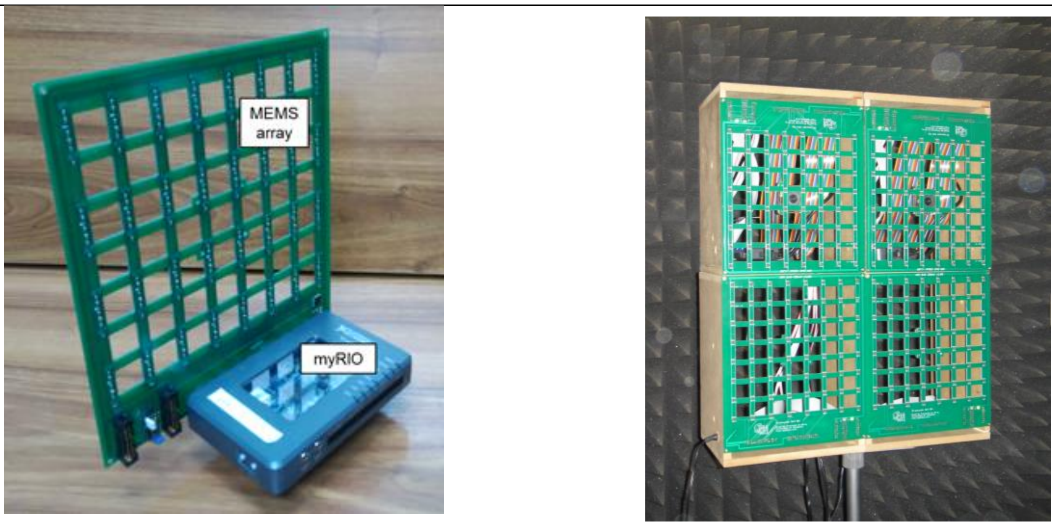
2. Hardware Setup

2.1. Processing and acquisition system

This section shows the acquisition and processing system used in this work [9], based on a 2D array of MEMS microphones. The acoustic images acquisition system used in this paper is based on 4 Uniform Planar Arrays (UPA) of 8x8 2.125cm-uniformly-spaced MEMS microphones, forming a bigger UPA of 16x16 sensors. This 8x8 array module and the 16x16 array are shown in Figure 1. The system implements the acquisition of the acoustic signals, using the MEMS array, and then the acquired signals are processed in order to generate the acoustic images, using wideband beamforming; as it is shown in Figure 2. The programming language used is NI LabVIEW 2017, along with its Real Time, FPGA, and GPU modules, which allows developing applications on different hardware platforms like those used in the system: FPGA, Embedded Processor (EP), PC, and GPU.

2.2. Test fan matrix

The system shown in the previous subsection has multiple applications: localization and characterization of noise or vibration sources, spatial filtering and elimination of acoustic interferences, etc.



(a) (b)

Figure 1. (a) Array module with myRIO and MEMS array board. (b) 16x16 array.

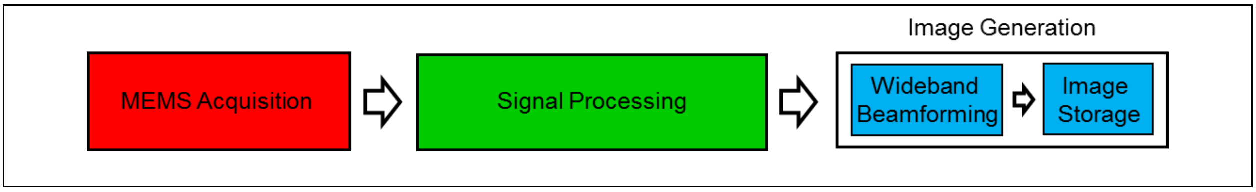


Figure 2. Software algorithms diagram.

(a) (b)

Figure 3. (a) Foxconn D90SM- 12 fan. (b) Fan matrix built for the test.

This study case is focused on obtaining acoustic images of a 3x3 fan matrix, specifically built to these tests with 9 coherent axial PC fans, which move the air in the direction of the fan axis. Each of the fans used to build the fan matrix is a Foxconn D90SM- 12 3-Pin with 7 blades. One of these fans is shown in Figure 3 (a), and Figure 3 (b) shows the fan matrix implemented for the tests. As it can be observed in Figure 3 (b), the fans of the matrix are controlled by a relay interface board that allows turning them on and off independently, in order to create different situations of faulty fans in fault diagnosis tests.

3. Analysis of the maxima position estimator

Previous studies of the authors [10-11] revealed that geometric parameters of the acoustic images of a working fan matrix, obtained using a planar array of MEMS microphones, could be used to detect if the matrix is not working properly.

In this study, the geometrical parameter selected to detect the fan matrix failure is the maximum of the acoustic images obtained for different frequencies. Particularly, it have been selected the maximum value and the position, expressed as an azimuth and an elevation pair of values.

The first step of this study was to analyse the acoustic signals received by the microphones of the array, to understand the noise generated by the fans of the matrix and to select the frequencies for which the acoustic images of the fan matrix are going to be obtained. As each fan has 7 blades and it rotates at 3500 rpm, its noise has harmonics at 400Hz. So, it was decided to work with the acoustic images at the harmonic frequencies between 400 Hz and 3600 Hz.

The analysis of the estimator is based on two different scenarios:

- In the first scenario, only one fan of the matrix is running.
- In the second scenario, the opposite scenario is supposed, all the fans of the matrix are running except one, that is, the fan has only one faulty fan.

For each scenario, 100 acoustic images have been obtained for each working situation of the system. That is, for each scenario, nine different working situations can be defined, each one corresponding with one running / faulty fan on the matrix.

3.1 First scenario: One running fan.

The variation of the position and the value of the maxima of the acoustic images of the fan matrix has been analyzed. Particularly, this analysis is based on the mean and the standard deviation (sigma) values of the azimuth and elevation coordinates of the maximum position, as well as the specific value of this maximum. This mean and standard deviation values have been obtained from the 100 acoustic images obtained for each running situation of the system.

Figure 4 shows, for this first scenario (only one fan of the matrix is running), the mean (first row) and standard deviation (second row) values for the position coordinates (first and second columns) and the specific value (third column) of the maximum of the acoustic image obtained for the selected working frequencies (400 Hz and its multiples, until 3600 kHz). In this figure 4, each coloured line represents a working situation of the system in this defined scenario. Each line matches with the corresponding working fan on the matrix.

In the first and second columns of Figure 4, it can be observed that for all the working frequencies, the mean value of the azimuth and elevation coordinates are nearly constant for the nine different working situations. For working frequencies lower than 2000 Hz, the standard deviations of the azimuth and elevation coordinates are high (until 2º and 4º). This could be a problem for the estimator. For higher working frequencies, the standard deviation values are low (0.4º), corresponding with a better behaviour of the estimator. In the first column of Figure 4, the three azimuth values corresponds with the real position of each column of the fan matrix. In the second column of Figure 4, the three elevation values corresonds with the real position of each row of the fan matrix.

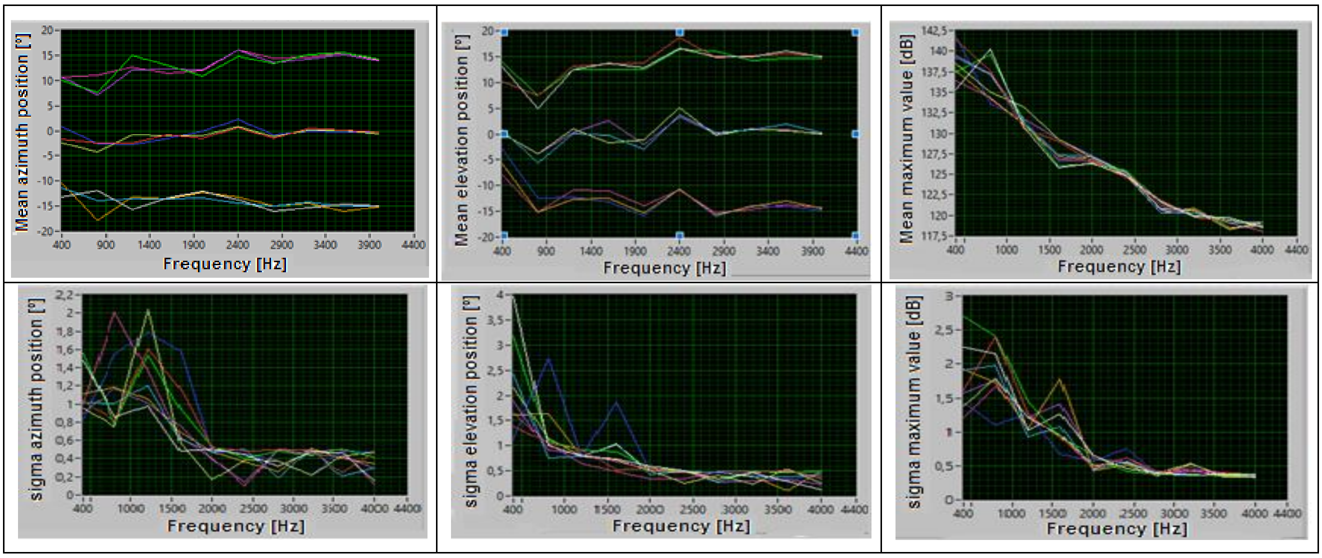


Figure 4. First scenario: only one fan is running. First column: Mean maximum position and value vs. frequency. Second column: Standard deviation of maximum position and value.

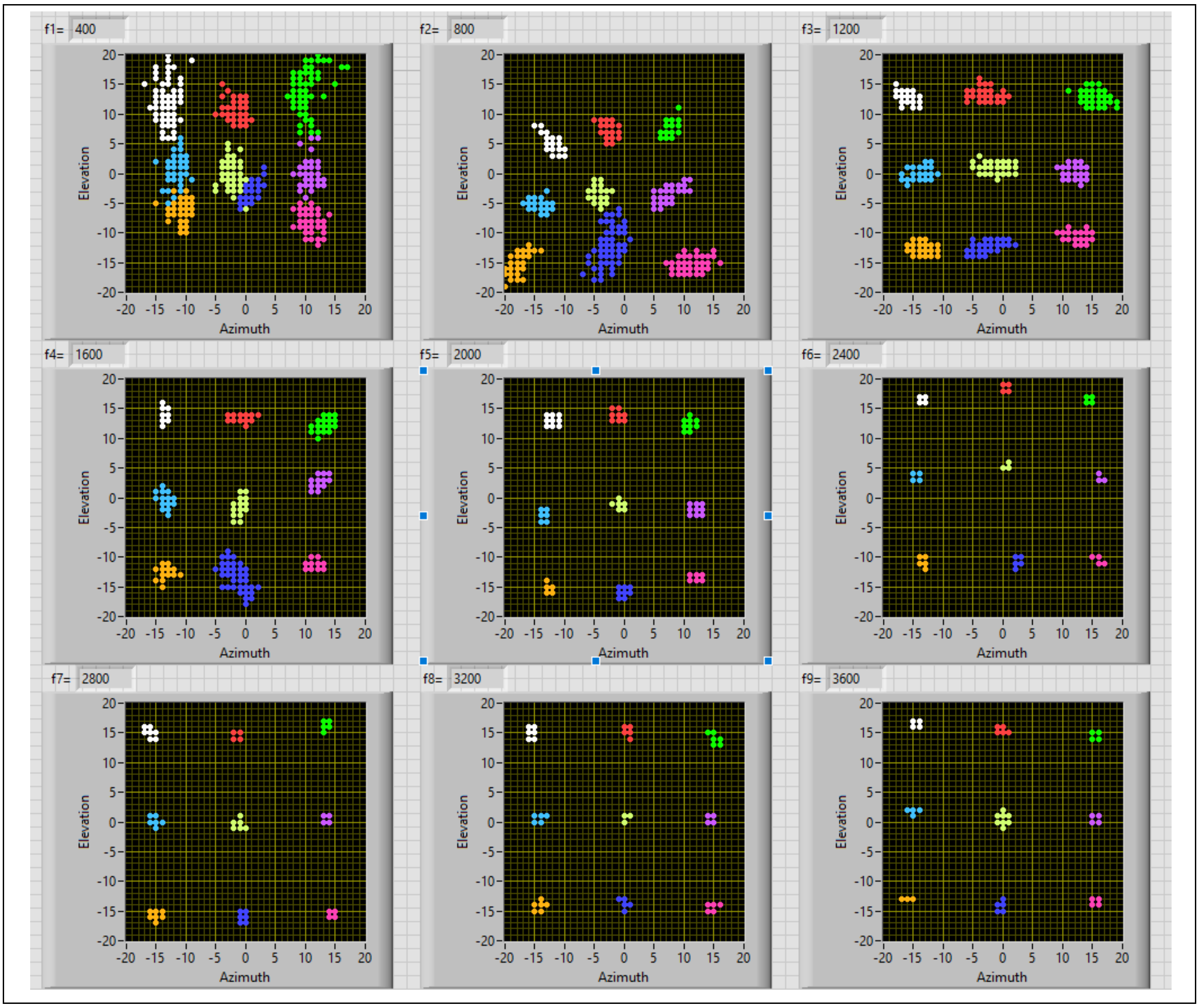


Figure 5. Maximum position dispersion vs. frequency for the first scenario (only one fan of the matrix is running).

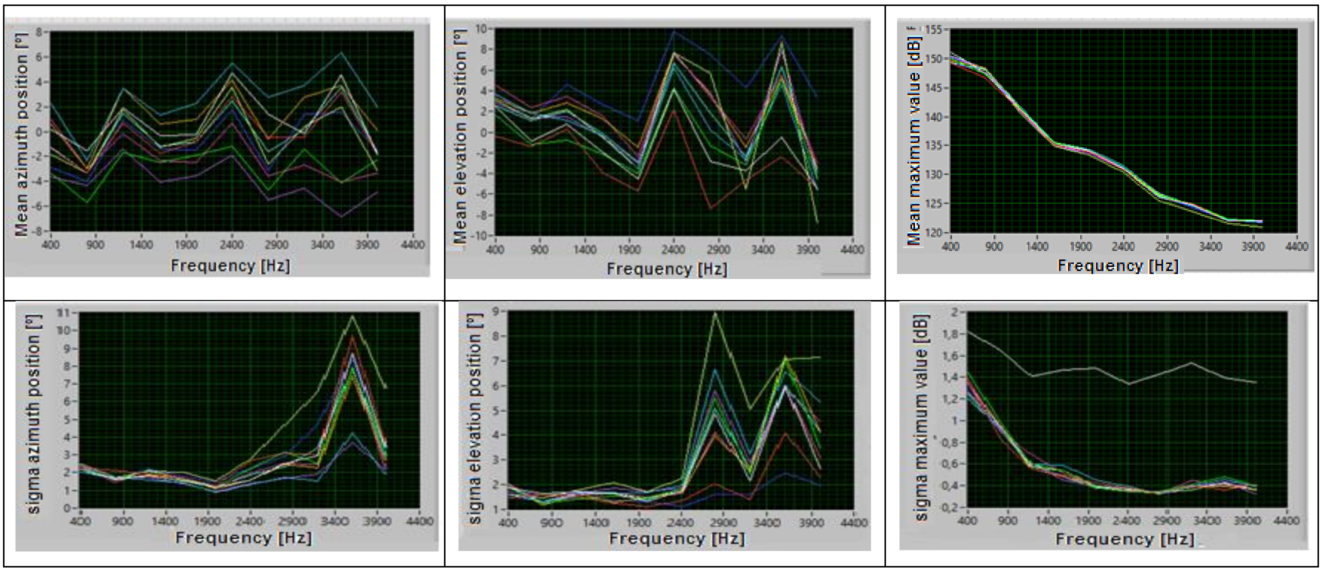


Figure 6. Second scenario: all the fans, except one, are running. First column: Mean maximum position and value vs. frequency. Second column: Standard deviation of maximum position and value.

In the third column of Figure 4, it can be observed that the maximum value decreases with the increasing frequency. It can also be observed that for the all nine working situations, the maximum values are very similar. As in the images corresponding with the maximum position coordinates, for working frequencies lower than 2000 Hz, the standard deviations of the maximum values are high (until 1.4dB), and for higher working frequencies, the standard deviation values are low (0.4dB). It seems that in the first scenario, the maximum value is not a good parameter to be used to differentiate between the nine working fans of the matrix.

Figure 5 shows, for the first scenario, the maximum position dispersion for the different working frequencies. In this figure, each coloured point represents the maximum position of one of the 100 acoustic images obtained for each working situation, i. e. for each working fan. It can be observed that the dispersion decreases with the increasing frequency. It seems that for all the frequencies, the estimator could differentiate which fan is working in each situation. For the two first frequencies (400 and 800 Hz), the position of the working fans are displaced; for 400 Hz, the fan positions are moved above, and for 800 Hz, the positions are moved below to the right.

3.2 Second scenario: One faulty fan.

Figure 6 shows, for the second scenario (all the fans of the matrix are running except one), the mean (first row) and standard deviation (second row) values for the position coordinates (first and second columns) and the specific value (third column) of the maximum of the acoustic image obtained for the selected working frequencies. In this case, each coloured line matches with the corresponding faulty fan on the matrix.

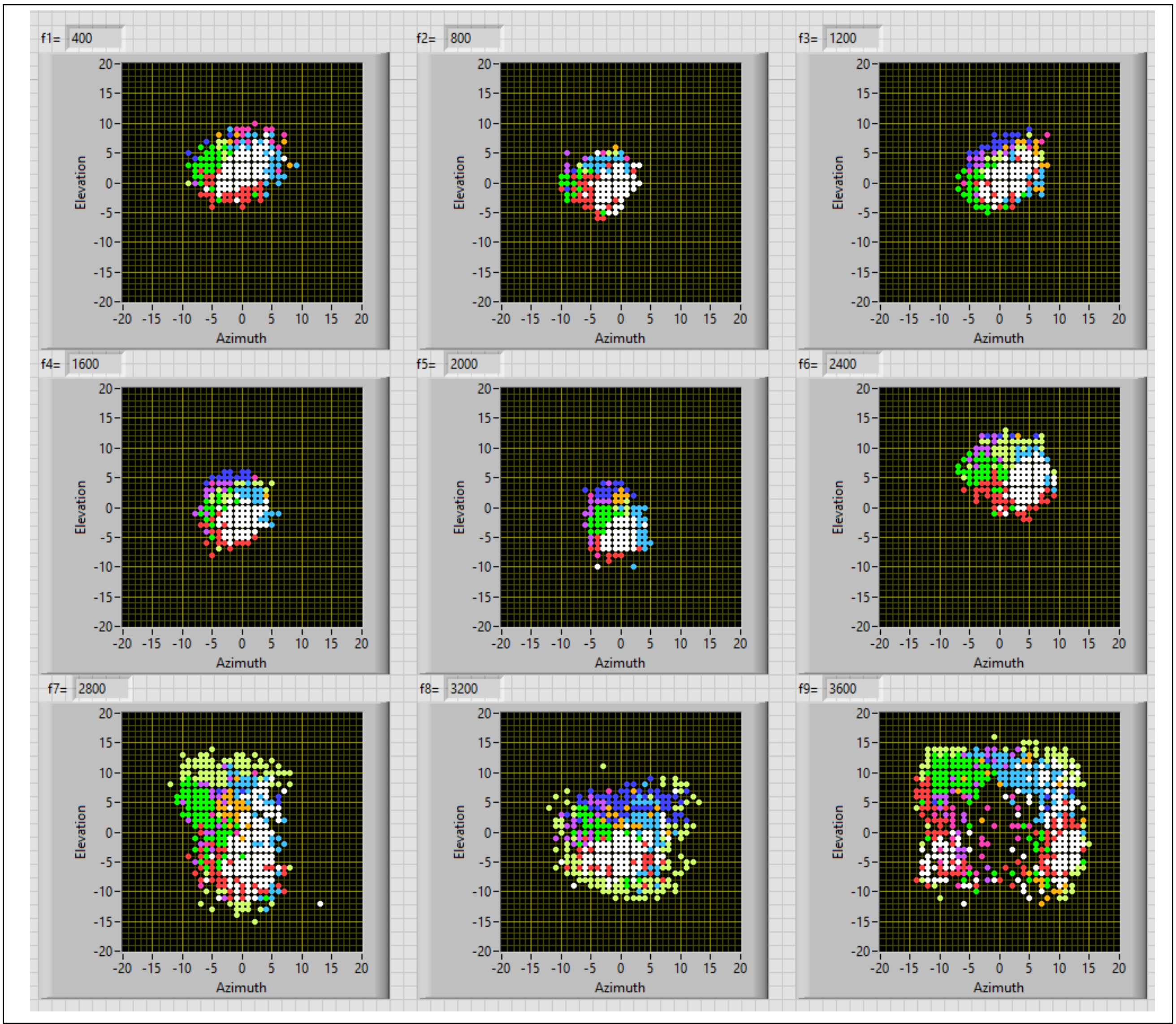


Figure 7. Maximum position dispersion vs. frequency for the second scenario (all the fans except one are running).

In this Figure 6, first and second columns show that for the nine working situations the behaviour of mean values of the azimuth and elevation coordinates are similar for the different working frequencies. Despite this similar behaviour, each working situation can be distinguisable, because each line is centered on a differente mean value. In this scenario, the corresponding standard deviation figures show that for low working frequencies the standard deviation values are low (1.5º),but for working frequency values higher than 2400 Hz, the standard deviation values are high (until 11º and 9º), and it becomes higher with larger frequencies. This is the reason why the researchers decided not to use this estimator on the second scenario, for working frequency values higher than 4000 Hz.

In the third column of Figure 6, as in Figure 4, it can be observed that the maximum value decreases with the increasing frequency and that for all working situations, the maximum values are very similar (between 150 and 120dB). In this case, the standard deviation behaviours are similar for all the working situations of the matrix, except one that shows higher values. In this second scenario, the maximum value is not again a good parameter to be used to differentiate between the corresponding nine working situations.

Figure 7 shows, for this second scenario, the maximum position dispersion for the different working frequencies. In this figure, each coloured point represents the maximum position of one of the 100 acoustic images obtained for each of the nine faulty fan situations.

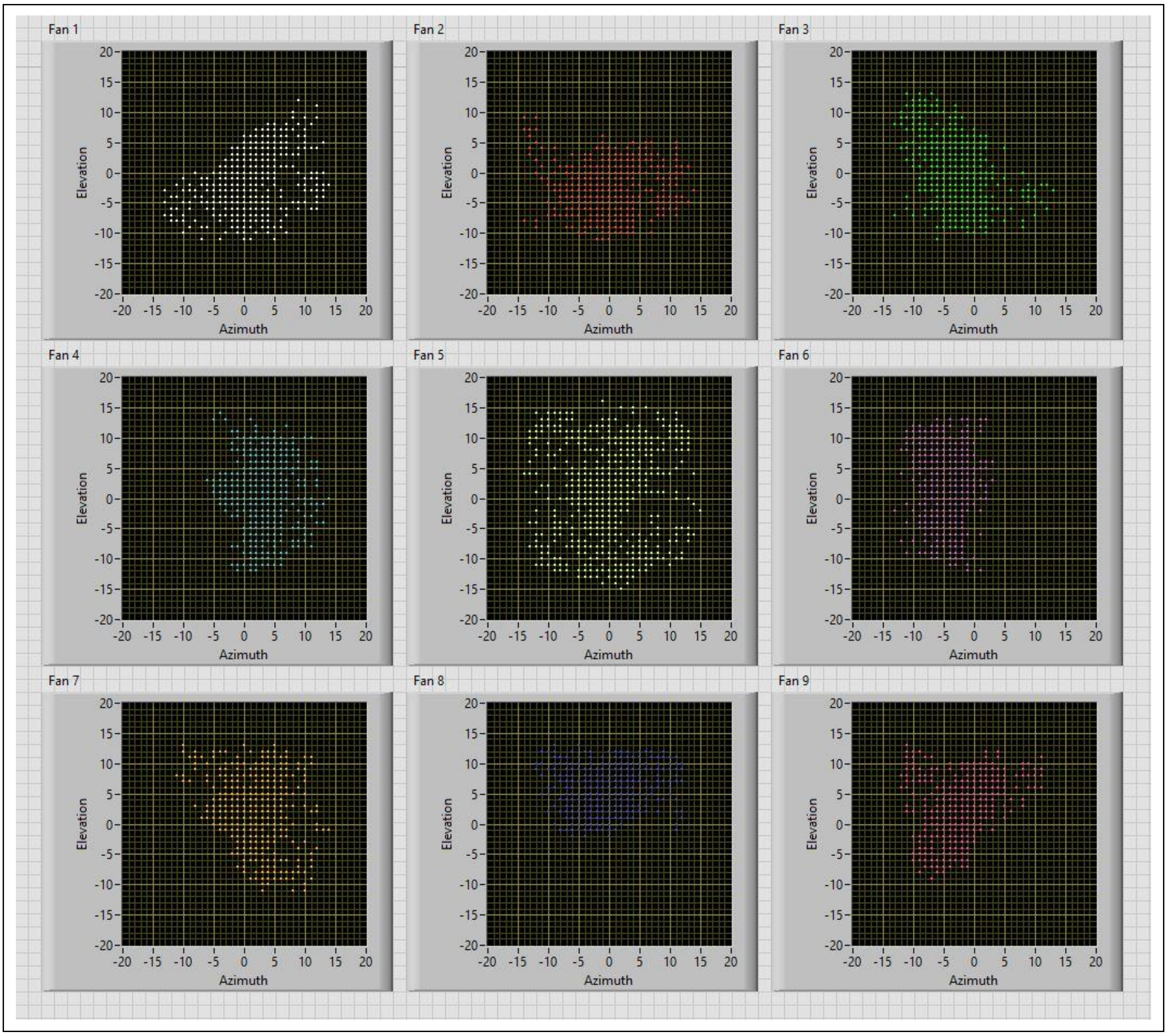


Figure 8. Maximum position dispersion vs. position of the faulty fan for the second scenario (all the fans except one are running).

In Figure 7, it can be observed that for all the frequencies, the maximum positions are mixed together for all the working situations, for all the faulty fans. It seems that for any frequency, the estimator could not be able to differentiate which fan is the faulty one in each situation.

Figure 8 shows, for this second scenario, the maximum position dispersion, in this case for each faulty fan situation. In this case, it can be observed that the positions of the maxima move to the opposite direction to the faulty fan position. The dispersion behaviour is different for each faulty fan situation. This fact makes the estimator reliable to be used to differentiate the working situations.

4. Conclusions

This paper has shown an analysis of the behavior of an estimator of the maxima positions of the acoustic images to be used to detect operation failures on the fans of a matrix. The analysis is based in two different scenarios: one in which only one fan is working on the matrix at the same time, and another one in which all fans of the matrix are working except one.

This analysis has drawn that the estimator is reliable for working frequencies of the system included between 400 Hz and 4000 Hz. It also has drawn that the positions of the maxima is a good parameter to differentiate working situations of the fan matrix, but the maximum values are not a good option to be considered as a parameter included on the estimator.

The maxima positions for each faulty fan situation show a dispersion that could be used to differentiate the working situations of the fan matrix. A future work associated to this analysis could be the use of geometric parameters of the dot clouds related to the maxima positions, in order to detect the corresponding faulty fan on the matrix.

Acknowledgement

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