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A failure detection methodology using new features of acoustic images of a fan matrix

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ABSTRACT

In previous studies of the authors, the acoustic images of a matrix of fans were used to detect operation failures on some fans. Promising results showed that maxima values and positions (azimuth and elevation) parameters of acoustic images of the fan matrix could be used to detect if one of the fans of the matrix is not working properly. The acoustic images were, obtained at different frequencies using a planar array of MEMS microphones. This developed methodology, based on a machine learning SVM algorithm, did not work properly if the matrix has more than one faulty fan. This work analyses the convenience of including other geometrical parameters or features of the acoustic images in the detection methodology. The new information that has been test to be used in the methodology is the centroid of the acoustic images and the energy included in the acoustic images on the vicinity of the real position of the fans in the matrix.

Keywords: Noise, Failure detection, Acoustic Images, Fan matrix
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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].

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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 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 [2]. 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 [3].

Arrays of MEMS microphones [4] are specially designed for acoustical imaging. 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 [5] to acquire and process acoustic images of a fan matrix [6-8], 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 fault diagnosis methodology to detect faulty behaviours 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 a planar array of MEMS microphones, using machine learning techniques.

On the first step of this research [6], 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 [7] carried out by the authors, these obtained acoustic images of a matrix of fans were used to detect operation failures on some fans. Next obtained results showed that the position and value of the maximum of the acoustic images could be used to detect if the fans were or were not working properly [8-9].

On the basis of these results, this work analyses the convenience of including other geometrical parameters or features of the acoustic images in the detection methodology. The new information that has been used in the methodology is the centroid of the acoustic images and the energy included in the acoustic images on the vicinity of the real position of the fans in the matrix.

2. HARDWARE SETUP

This section shows the acquisition and processing system used in this work [4-5], 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.

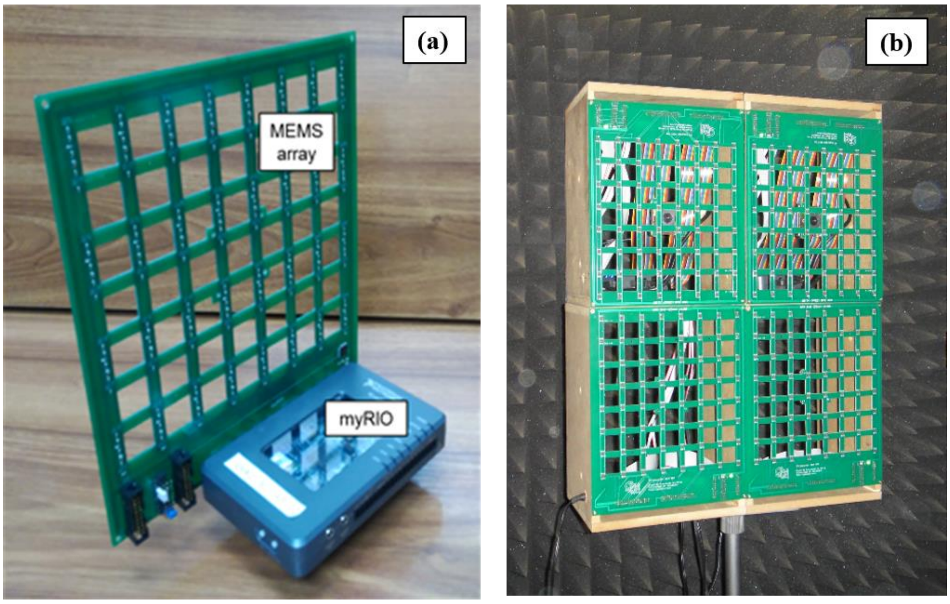


Figure 1. (a) Array module with myRIO and MEMS array board. (b) 16x16 array.

The system implements the acquisition of the acoustic signals, using the 16x16 MEMS array, and then the acquired signals are processed in order to generate the acoustic images, using wideband beamforming. This system has multiple applications: localization and characterization of noise or vibration sources, spatial filtering and elimination of acoustic interferences, etc.

This work is focused on obtaining acoustic images of a 3x3 fan matrix, shown in Figure 2, placed 50 cm opposite the 16x16 MEMS array. Each of the fans used to build the fan matrix is a Sunon MagLev ME80251V1, with 7 blades. 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.

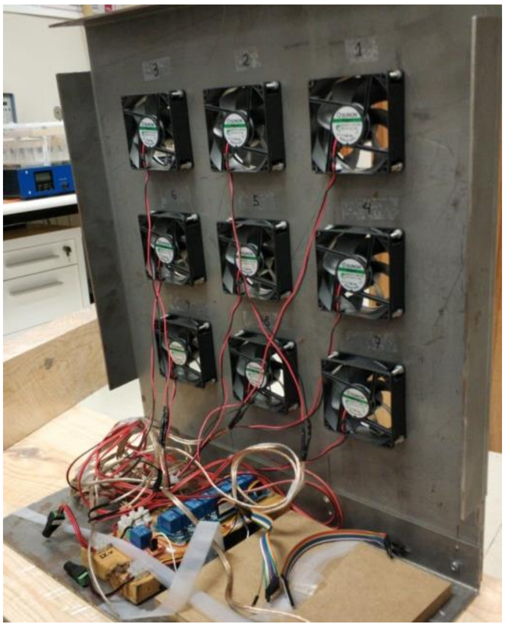


Figure 2. Test fan matrix

3. ANALYSIS OF NEW GEOMETRIC PARAMETERS OF THE ACOUSTIC IMAGES

Previous studies of the authors [7-8] 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. These used geometric parameters were the maximum value and the position (azimuth and elevation) of the acoustic images obtained for different frequencies. As each fan had 7 blades and it rotated at 3500 rpm, its noise had harmonics at 400Hz. So, it was decided to work with the 100 acoustic images at the harmonic frequencies between 400 Hz and 3600 Hz, in a scenario where all the fans of the matrix were running except one, that is, the matrix had only one faulty fan. So, nine different working situations were defined, each one corresponding with one fan of the matrix. These studies [7-8] also revealed that some other geometric parameters could be used to detect faulty working situations on the matrix.

Results obtained in these previous studies [7-8] showed that the positions of the maxima moved to the opposite direction to the faulty fan position, as can be observed in Figure 3. The position of each faulty fan is represented with a red cross. The dispersion behaviour of these maxima was different for each faulty fan situation. This behaviour showed the authors that other geometric features of the acoustic images could be used to detect faulty working situations on the fan matrix.

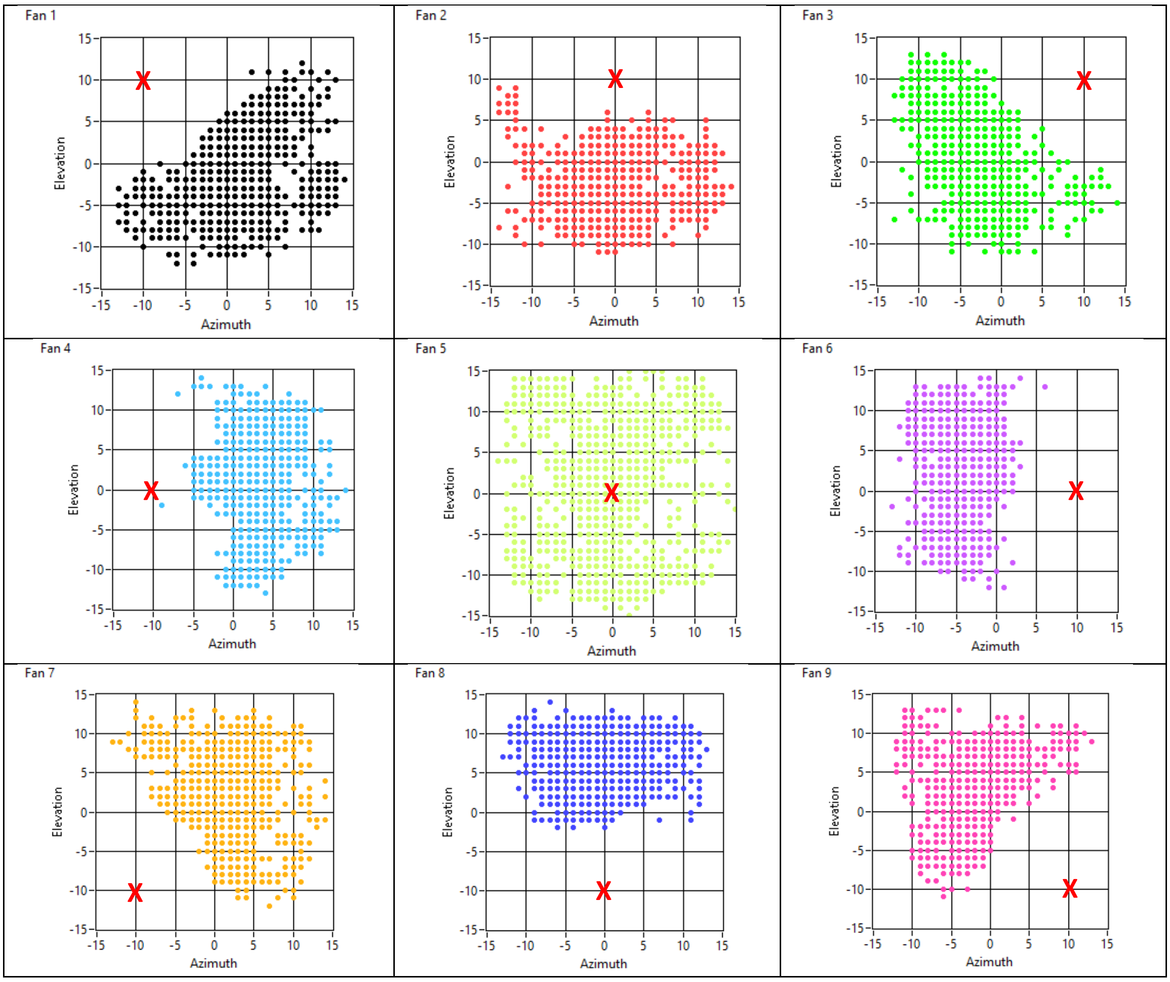


Figure 3. Maximum position dispersion for each faulty fan situation

So, the study shown in this work is focused in the analysis of the centroid and the energy included in the acoustic images on the vicinity of the real position of the fans in the matrix, as new geometric parameters to be used to detect faulty working situations on the fan matrix. As in the previous studies [7-8], the same scenario, where the matrix had only one faulty fan, was defined. And it was decided to work with 200 acoustic images at the harmonic frequencies between 400 Hz and 3600 Hz, for each working situation of the matrix, that is, for each faulty fan.

3.1 Analysis of the centroids of the acoustic images

In this analysis, the centroids of the acoustic images for the defined working frequencies have been obtained for each faulty fan situation. Figure 4 shows in each image, which corresponds with each faulty fan situation, the centroid position dispersion considering all the working frequencies. The position of each faulty fan is represented with a red cross.

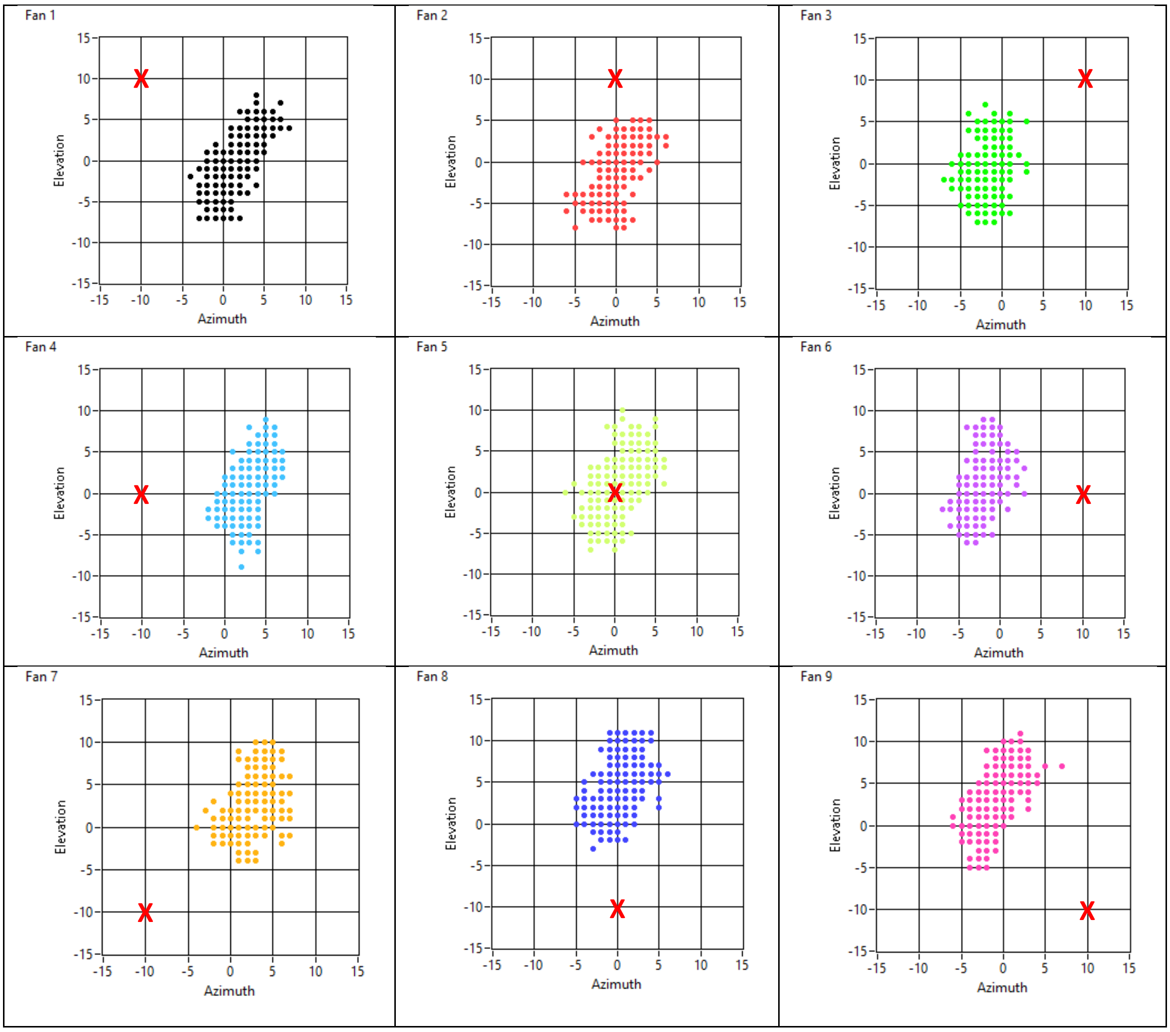


Figure 4. Centroid position dispersion for each faulty fan situation

Comparing these results, with the results obtained for the maxima position dispersion, shown in Figure 3, it can be observed that in this case, the behaviour of the centroid positions is not so clear. The dot clouds are more concentrated, are very similar for the 9 different working situations. Now, it is not so clear that the dot clouds move to the opposite direction to the position of the faulty fan. It is clear that the centroid positions move away from the position of the faulty fan position, but it seems that all the clouds move more or less to the centre of the image. With only this information it is not clear if the centroid positions are or not a good geometric parameter to be used to differentiate the fan matrix working situations.

3.2 Analysis of the energy contained in the acoustic images

In the second analysis, the energy contained in the acoustic images on the vicinity of the real position of the fans in the matrix has been obtained, for each faulty fan situation, for each working frequency. Figure 5 shows, as an example, the energy distribution in the acoustic images for the 3600 Hz working frequency. Each image of the figure corresponds with each faulty fan working situation. The position of each faulty fan is represented with a red cross, and it can be observed that the energy contained in the acoustic images decreases on the vicinity of position of the faulty fan.

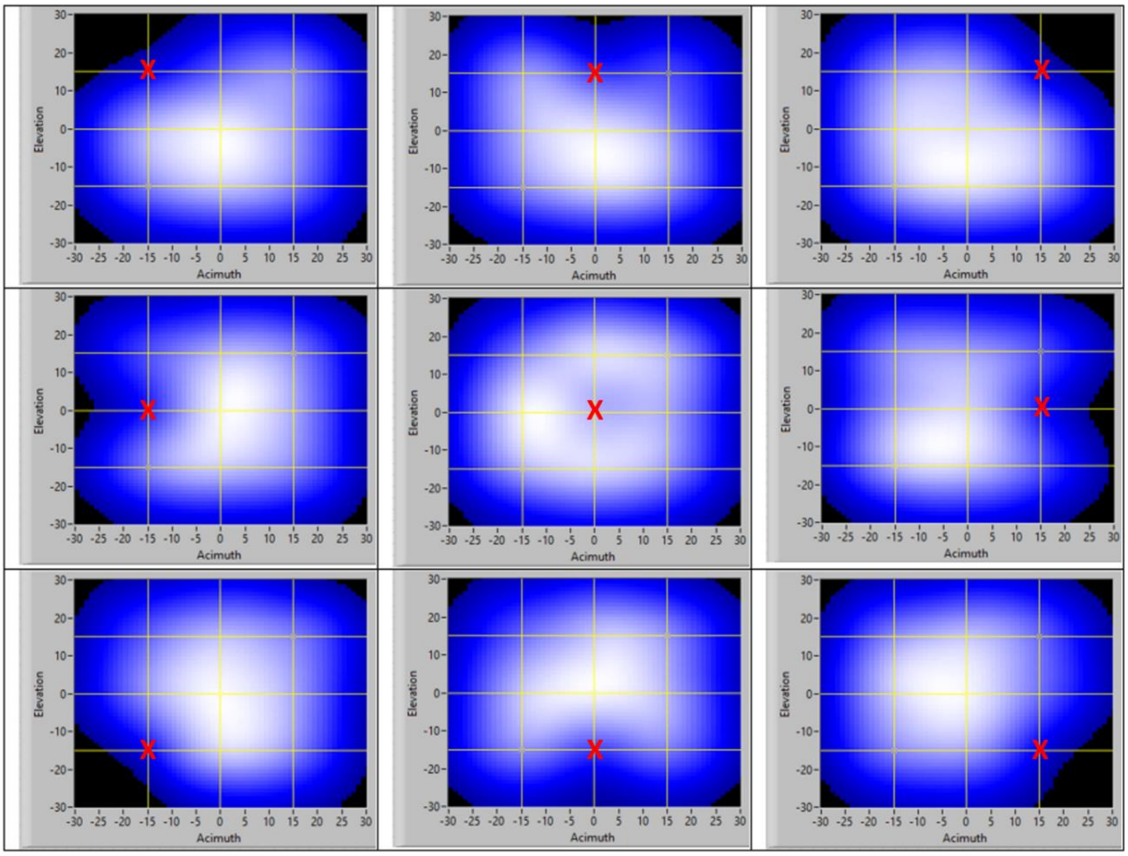


Figure 5. Energy distribution (f=3600Hz) for each faulty fan situation

The acoustic images have been divided into 9 areas, each one centred on the position of each of the 9 fans of the matrix. For each working frequency, for each acoustic image of the 200 ones obtained for each faulty fan situation, the energy contained in each of these 9 areas has been assessed.

The authors have analyzed the behavior of these energy values, and they have observed that for each faulty fan situation, and for each specific working frequency, the energy values for the 200 acoustic images oscillate around a certain mean value. This behavior of the energy values is equivalent for each of the 9 areas around the positions of the fans.

Figure 6 shows these energy values for the 200 acoustic images for the 3600 Hz working frequency, for 3 different faulty fan situations. Each image of Figure 6 shows the 200 energy values of the 9 areas around the 9 positions of the fans of the matrix. In each of these images, energy values related to the same area around the position of a fan are represented in the same color.

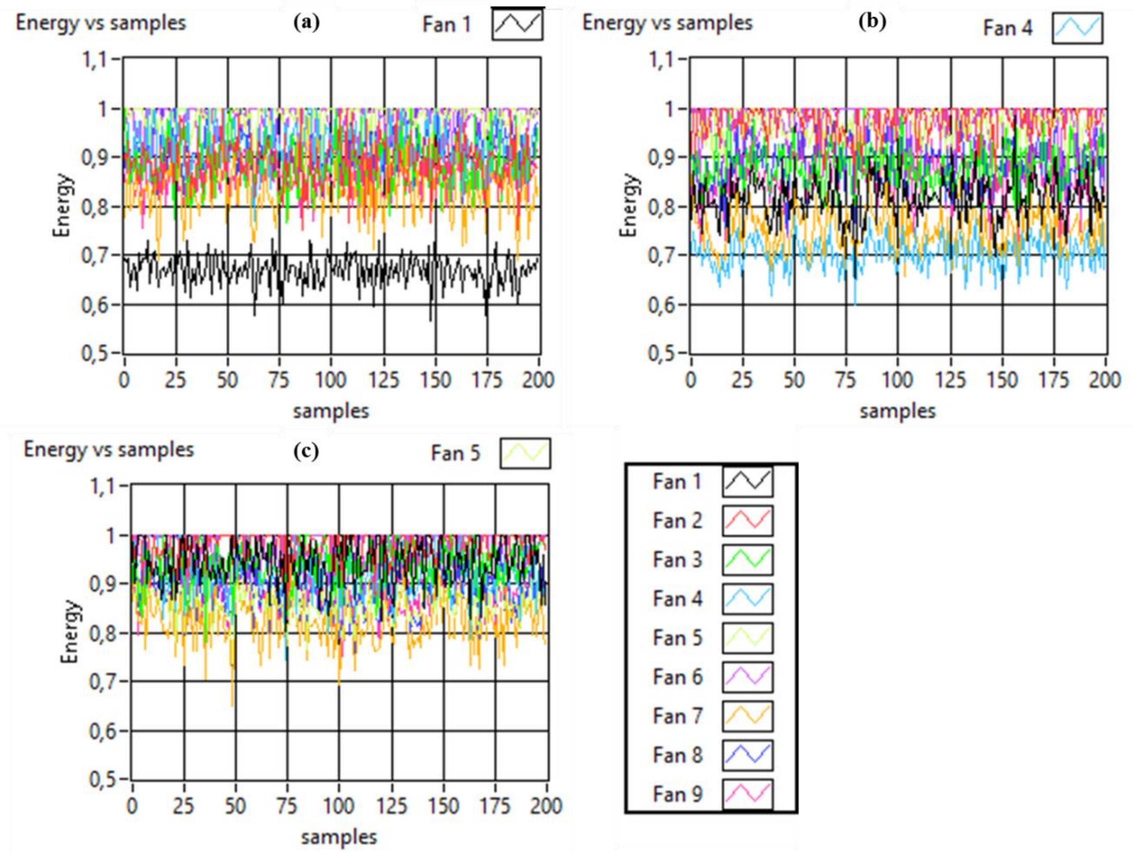


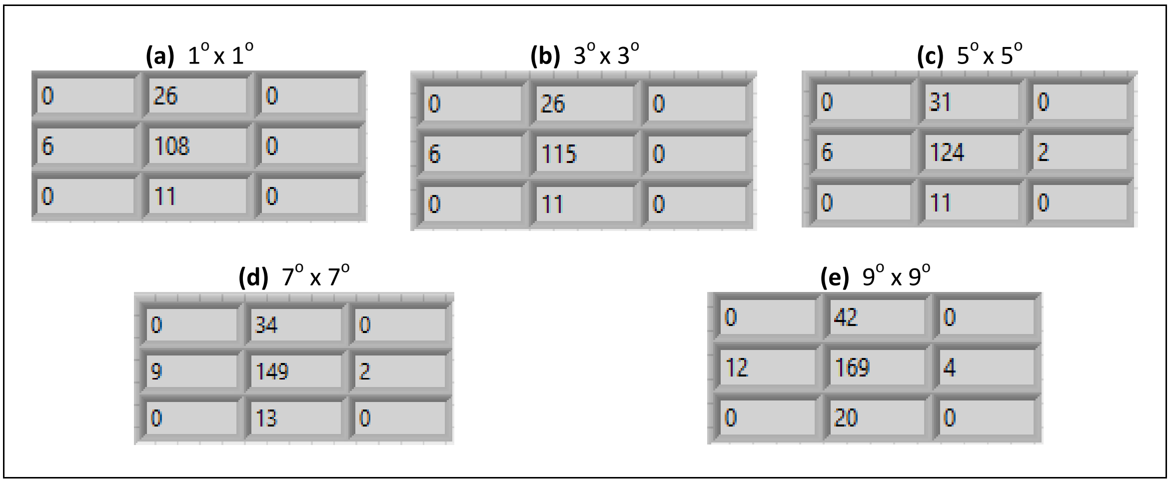
Figure 6. Energy values images (f=3600 Hz) on the areas around the fan positions, for 3 faulty fan situations: (a) Fan 1, (b) Fan 4, and (c) Fan 5.

Figure 6a shows the energy values obtained for the matrix working situation where Fan 1 is the faulty fan, as an example of a fan matrix where one of the fans on the corners of the matrix is not working properly. It can be observed that the energy values on the vicinity of the position of fan 1, which is the faulty fan, are different from the other ones. These values are lower, representing that there is less energy around the vicinity of fan 1. The reason of this energy decrement is that the corresponding fan is not working. So, this energy information seems to be really useful to detect if a fan on the corners of the matrix is not working properly.

Figure 6b shows the energy values obtained for the matrix working situation where Fan 4 is the faulty fan, as an example of a fan matrix where one of the fans on the sides of the matrix is not working properly. It can be observed that the energy values on the vicinity of the position of fan 4, which is the faulty fan in this case, are the lower ones, but the difference with the energy values of the other areas is not as clear as in the values shown in Figure 6a. As these values are the lowest, this fact also represents that there is less energy around the vicinity of fan 4, because it is the faulty one. In this case, this energy information could be useful to detect if a fan on the sides of the matrix is not working properly.

Figure 6c shows the energy values obtained for the matrix working situation where Fan 5 is the faulty fan, as an example of a fan matrix where the fan placed on the center of the matrix is not working properly. It can be observed that the energy values on the vicinity of the position of fan 5, the faulty fan, are not distinguishable among the other energy values. In this case, the energy information seems to be useless to detect if the fan on the center of the matrix is not working properly.

Some analyses have been carried out considering that in each working situation, the area around the corresponding faulty fan should be the one with the lowest energy value. These analyses considered different area sizes (azimuth x elevation widths): 1º x 1º, 3º x 3º, 5º x 5º, 7º x 7º and 9º x 9º. All these areas were centered on the real position of the fans in the matrix. The energy contained in each area have been assessed for each working frequency and for each of the 200 acoustic images obtained for each faulty fan situation. And it have been checked if the lowest energy value corresponds with the area on the position of the faulty fan. Figure 7 shows the times that the lowest energy value does not match with the area of the corresponding faulty fan, that is, the number of errors on this faulty fan detection methodology.



(a) 1° x 1°

0	26	0
6	108	0
0	11	0

(b) 3° x 3°

0	26	0
6	115	0
0	11	0

(c) 5° x 5°

0	31	0
6	124	2
0	11	0

(d) 7° x 7°

0	34	0
9	149	2
0	13	0

(e) 9° x 9°

0	42	0
12	169	4
0	20	0

Figure 7. Number of errors in the detection of the corresponding faulty fan (f=3600Hz), for different sizes of the areas in the vicinity of the positions of the fans where the energy is assessed.

Figure 7a shows the errors when the area size is 1º x 1º. This area corresponds with the real positions of the fans. It can be observed that the faulty fan detection methodology works if the faulty fan is placed on one of the corners of the matrix, as it has been counted no errors at those positions. It can also be observed that the number of errors if the center fan is the faulty one is high. In this case the methodology shows a 54% error rate, as it shows 108 errors of the 200 possibilities for the specific faulty fan.

If the area size is bigger (Figures 7b-e), it can be observed that the number of counted errors increases. Considering a 9º x 9º area size, the error rate for the center faulty fan rises to 84.5%. It can also be observed that this detection methodology always works if the faulty fan is one of the corners. This data do not seem to be really reliable for all the possible working situations defined, only one faulty fan.

4. CONCLUSIONS

At first glance, centroids are not a good geometric parameter of the acoustic images to be used in the detection of faulty working situations on a fan matrix. On their part, energy values are promising, as they show a good behavior on the detection of most of the faulty fans.

These data seems not to be totally reliable for all the working situations, but it should be a good idea to train a Support Vector Machine (SVM) classifier to detect faulty fans on a matrix. This SVM classifier could use these data independently, that is, using only centroid data or energy data; or the classifier could use both data at the same time. These data could also be combined with the maxima data of the acoustic images, in order to train the SVM classifier and improve the fault, in order to train the SVM classifier and improve the fault fan detection methodology.

5. ACKNOWLEDGEMENTS

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