Fault Detection Methodology for a Fan Matrix based on SVM Classification of Acoustic Images

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Abstract. A methodology to detect if a fan matrix is working properly has been designed and is presented in this paper. This methodology is based on a Support Vector Machine (SVM) classifier that uses geometrical parameters of the acoustic images of the fan matrix. These acoustic images have been obtained using a 16x16 planar array of MEMS microphones working at different frequencies. A fan matrix that is not working properly implies that some of its fans have failed, that is, it does not work. The designed fault detection methodology supposes that these fans fail one by one. If one of the fans is not working, this fact can be detected rapidly with the purposed methodology, and the fan can be repaired or replaced by a new one. Although it is really unusual that more than one fan fails at the same time, this paper also studies how this methodology works if the number of faulty fans increases, in order to know if the methodology is robust enough in the presence of unexpected situations.

Keywords: Fault detection, fan matrix, acoustic images, SVM.

1 Introduction

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 [1]. 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. It is a major component of predictive maintenance. 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. Condition monitoring techniques are normally used on rotating equipment, auxiliary systems and other machinery (compressors, pumps, electric motors, internal combustion engines, presses) [2].

Engineers have used vibration based analysis for decades to evaluate the condition of complex mechanical systems such as rotating machinery [3,4]. In these cases, the difficulty arises when trying to relate faults with observable quantities, and many times these relations are subject to human interpretation [5]. To avoid this subjective interpretation, an automatic methodology should be desirable. The classic approach for monitoring 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 [6].

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 it known that 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 pattern [7]. There are many examples of the use of microphone arrays in acoustic imaging systems.to measure this acoustic field [6-9].

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 [10]. By using beamforming techniques [11], 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 [12] to acquire and process acoustic images of a fan matrix [13], 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.

The failure detection methodology shown in this paper is based on a Support Vector Machine (SVM) classifier that uses geometrical parameters of the acoustic images of the fan matrix, as they offer useful information [14]. The acoustic images of the fan matrix have been obtained using a 16x16 planar array of MEMS microphones working at different frequencies. The designed fault detection methodology supposes that the fans of the matrix fail one by one. If one of the fans is not working, this fact can be detected rapidly with the purposed methodology, and the fan can be repaired or replaced by a new one. It has been observed that the effect of the corresponding faulty fan is shown on the geometry of the acoustic image of the fan matrix [15].

2. Hardware Setup

2.1 Processing and acquisition system

This section shows the acquisition and processing system used in this work [12], 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.

(a) (b)

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

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 2015, 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.

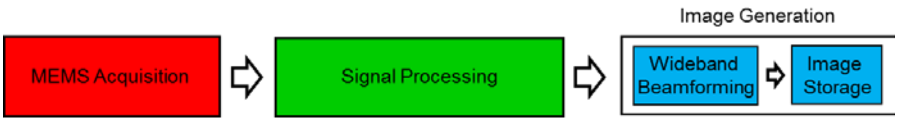

Fig. 2. Software algorithms diagram

2.2 Test fan matrix

The system shown in previous sections has multiple applications: localization and characterization of noise or vibration sources, spatial filtering and elimination of acoustic interferences, etc. 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 on and off the fans of the matrix independently, in order to create different situations of faulty fans in fault diagnosis tests.

(a) (b)

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

3 Fault diagnosis methodology

3.1 Accuracy of the methodology considering a one-faulty-fan situation

Some tests have been developed to obtained acoustic images of a fan matrix. These tests have been carried out inside an anechoic chamber, using the acoustic system developed by the research group [12]. The fan matrix has been placed 50 cm opposite the 16x16 MEMS array. These tests have allowed the authors to obtain acoustic images of the fan matrix with only one faulty fan, as well as acoustic images of the whole working fan matrix, i.e. with the nine fans working at the same time. As it has been pointed previously, the designed fault detection methodology showed in this paper supposes that if the fans of the matrix fail, they fail one by one.

The acoustic signals received by the microphones of the array have been analyzed in order to understand the noise generated by the fans of the matrix. As each fan has 7 blades and it rotates at 3500 rpm, its noise has harmonics at 400Hz, and its multiples. After a previous study [15], it was decided to work with the acoustic images at the harmonic frequencies between 400 Hz and 4 kHz. And a machine learning algorithm, based on a linear Support Vector Machine (SVM), has been used to detect the faulty fan position, using some geometrical parameters of the acoustic images that have been obtained at the selected frequencies. For this particular work, the geometrical parameters which have been used are the value and the position of the maxima of these acoustic images [14].

It has been noticed that if one fan fails, the maximum position and value of the acoustic image change. One of these effects can be observed on Figure 4, which shows the maximum positions of different acoustic images of the fan matrix with one faulty fan, whose real position is showed as a red cross.

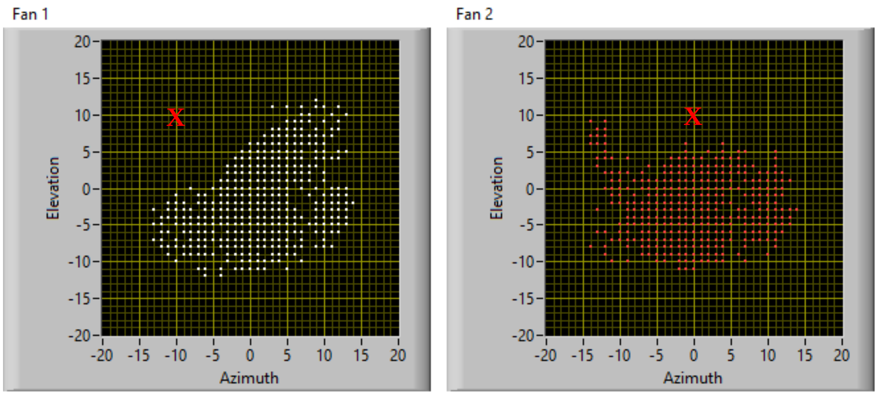

Fig. 4. Maximum positions of the acoustic images of fan matrix with one faulty fan (the position of this faulty fan is represented with a red cross).

After obtaining these geometrical parameters of the acoustic images, they are given to the classification algorithm, based on a linear SVM, in order to detect which fan is not working properly. The obtained accuracy rate for the SVM algorithm is 95.6%. This result shows that the purposed methodology is reliable when one fan of the matrix fails, because it detects the faulty fan position.

3.2 Robustness analysis of the fault diagnosis methodology under two-faulty-fans situations

Although it is really unusual that more than one fan fails at the same time, this paper also studies how this methodology works if the number of faulty fans increases, in order to know if the methodology is robust enough in the presence of unexpected situations.

To analyze this robustness, the SVM classifier has been trained with the geometrical parameters of the acoustic images corresponding to the situations where the matrix has only one faulty fan, as in the previous section. But then, this classifier has been validated with the geometrical parameters of acoustic images corresponding to situations where the matrix has two faulty fans.

Six different combinations of the pair of faulty fans, shown in red in Figure 5, have been tested:

- Case 1: Two fans located on both ends of the largest diagonal of the matrix.
- Case 2: Two fans located on both ends of one row or one column of the matrix.
- Case 3: Two fans located on both ends of the “L-shaped” movement in chess.
- Case 4: Two fans separated one diagonal step.
- Case 5: One fan in the centre of the matrix, and the other one separated one vertical/horizontal step.
- Case 6: Two fans separated one vertical/horizontal step, and none is in the centre of the matrix.

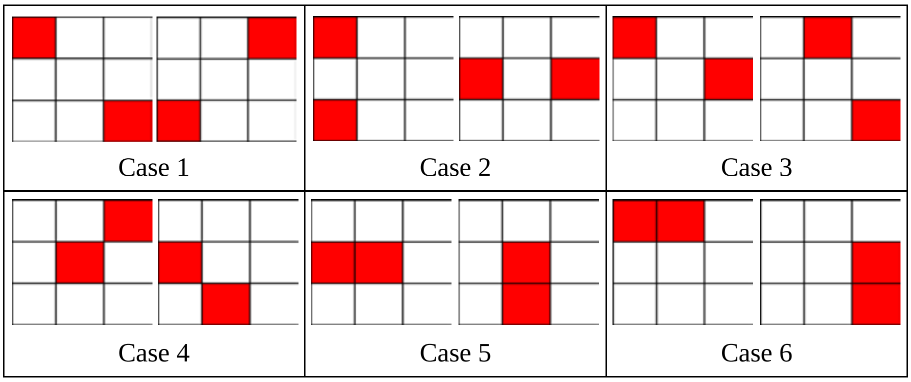

Fig. 5. Examples of the tested two-faulty-fans combinations, shown in red.

The accuracy rate results, obtained by the SVM algorithm, in this robustness analysis are shown in Table 1. These results show that as the two faulty fans are more separated, the accuracy of the algorithm to detect one of the fans that is not working as faulty decreases. In these tests, although in most cases the SVM classifier can't identify correctly which are the faulty fans, but it can alert if there is a problem with the fan matrix, it alerts if the matrix is not working properly.

Table 1. SVM accuracy rates.

Test	Accuracy Rate
1 faulty fan validation:	95.6%
2 faulty fans validation:	
Case 1	10.9%
Case 2	14.2%
Case 3	14.7%
Case 4	23.5%
Case 5	44.1%
Case 6	48.3%

4 Conclusions

This paper shows a fault detection methodology developed to detect if one fan of a fan matrix is not working properly. This methodology, based on geometrical parameters of acoustic images of the fan matrix and in a Support Vector Machine algorithm, is reliable when only one fan of the matrix is not working.

This methodology has been designed for these specific situations, obtaining a really good accuracy rate. But its robustness under other unexpected circumstances, i.e. with more than one faulty fan on the matrix at the same time, has also been analyzed. This analysis has shown that this methodology fails if more than one fan fails at the same time. Under this circumstance, the methodology does not detect which are the faulty fans. But it detects successfully that the matrix is not working properly.

Future work must be done to solve this limitation. One solution could be training the SVM algorithm to detect individual failures for each fan of the matrix.

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References

1 Reppa V, Tzes A (2009) Fault detection and diagnosis based on parameter set estimation. IET Control Theory and Applications 5(1):69-83. doi: 10.1049/iet-cta.2009.0202.
2 Jardine AKS, Lin D, Banjevic D (2006). A review on machinery diagnostics and prognostics implementing condition-based maintenance. Mechanical Systems and Signal Processing. 20(7):1483–1510. doi:10.1016/j.ymssp.2005.09.012.
3 Haddar M, Bartelmus W, Chaari F, Zimroz R, Applied Condition Monitoring, Book series, Springer, ISSN: 2363-698X.
4 Dalpiaz G, Rubini R, D'Elia G, Cocconcelli M, Chaari F, Zimroz R, Bartelmus W, Haddar M (2013) Advances in Condition monitoring of Machinery in Non-Stationary Operations, Proceedings of the third International Conference Condition Monitoring of .Machinery in Non-Stationary Operations CMMNO'2013. ISBN: 978-3-642-39348-8.
5 Lu Y, Tang J, Luo H (2012) Wind turbine gearbox fault detection using multiple sensors with features level data fusion. Journal of Engineering for Gas Turbines and Power, 134:042501-1-8. doi: 10.1115/1.4004438.
6 Ravetta P, Muract J, Burdisso R (2007) Feasibility study of microphone phased array based machinery health monitoring. Mecánica Computacional, 26:23-37.
7 Lu W, Jiang W, Yuan G, Yan L (2013) A gearbox fault diagnosis scheme based on near-field acoustic holography and spatial distribution features of sound field. Journal of Sound and Vibration, 332:2593-2610. doi: 10.1016/j.jsv.2012.12.018.
8 Herold G, Sarradj E (2015) Microphone array method for the characterization of rotating sound sources in axial fans. Noise Control Engineering Journal, 63(6):546-551. doi: 10.3397/1/376348.
9 Zenger F et al. (2016) Sound source localization on an axial fan at different operating points. Experiments in Fluids, 57:136. doi: 10.1007/s00348-016-2223-8.
10 Van Trees, H. (2002) Optimum array processing: Part IV of Detection, estimation and modulation Theory, John Wiley & Sons: New York, USA.
11 Van Veen BD, Buckley KM (1988) Beamforming: A versatile approach to spatial filtering. IEEE ASSP Magazine, 1988:4-24.doi: 10.1109/53.665.
12 Izquierdo A, et al. (2016) Design and evaluation of a scalable and reconfigurable multiplatform system for acoustic imaging. Sensors, 16(10):1671. doi: 10.3390/s16101671.
13 del Val L, et al. (2017) Using a planar array of MEMS microphones to obtain acoustic images of a fan matrix. Journal of Sensors, 2017: article ID 3209142. doi: 10.1155/2017/3209142.
14 del Val L, et al. (2017) First steps on fan matrix condition monitoring and fault diagnosis using an array of digital MEMS microphones. Proceedings of Meetings on Acoustics, 30:030014. doi: 10.1121/2.0000656.
15 del Val L, et al. (2018) Analysis of a maxima position estimator on acoustic images of a fan matrix for failure detection. In Proceedings of the Euronoise 2018 Conference, Crete, May 2018.

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