Jaroslaw RZEPECKI, Stanislaw WRONA, Anna CHRAPONSKA, Krzysztof MAZUR, Marek PAWELCZYK
Politechnika Śląska

KAMERA AKUSTYCZNA JAKO UNIWERSALNE NARZĘDZIE DO POMIARU EMISJI AKUSTYCZNEJ URZĄDZEŃ

Streszczenie. W artykule zaprezentowano wszechstronne zastosowanie kamery akustycznej jako urządzenia lokalizującego źródła niepożądanych dźwięków. W badaniach ujęto różne sytuacje: usterka silnika elektrycznego, nieszczelność chłodnicy, wzbudzające się elementy elektroniczne, emisja akustyczna urządzenia AGD oraz wentylatora podłogowego. Testy przeprowadzono na skonstruowanym wcześniej prototypie kamery akustycznej, bazującym na płaskiej, spiralnej macierzy mikrofonów oraz kamerze wizyjnej 2D.

ACOUSTIC CAMERA AS AN UNIVERSAL TOOL TO MEASURE ACOUSTIC EMISSION OF DEVICES

Summary. The paper presents a comprehensive use of acoustic camera as a device for localisation of the undesirable sound sources. The research covered various situations: electrical motor failure, cooler leakage, noisy electronic components and acoustic emission of household appliance and floor-standing fan. The tests were performed on a previously constructed acoustic camera prototype, based on a flat spiral array of microphones and a 2D vision camera.

1. Introduction

Acoustic camera is a device, which is widely used for localisation of noise sources in many areas. In automotive industry, one of the crucial factors of the product quality is acoustics of the vehicle interior. It is defined by minimisation of the buzz, squeak and rattle sounds (BSR). Therefore, if any undesirable sounds appear, it is possible to localise their sources using acoustic camera [2, 10]. This device also helps to improve other acoustical properties of the car prototype, before starting of the mass production, e.g. during the test in wind tunnel [12]. This is the validation of the aerodynamics and tightness of the vehicle interior. In addition to the automotive, similar tests are carried out in the aircraft industry, e.g. for helicopters [1]. There are also other ways to use the acoustic camera, e.g. for localisation of the most noisy parts of the wind turbines [8] or in environment protection for cancellation of the noise from moving vehicles [15]. On the other hand, there are situations, when appearance of a sound is desirable, as in case of communication and cooperation between human and the machine [9] and in speaker localisation or speech recognition [6]. Generally, acoustic camera is used for getting information about position of the sound source in one, two or three dimensions, which depends on the microphone array construction and the number of vision cameras.

In this paper authors focus on utility of the acoustic camera in localisation of the sources of the undesirable sounds, e.g. in non-destructive diagnostics. The experiments were performed for various situations and based on five different objects: damaged and undamaged electric motors, floor-standing fan, leaky cooler, untight casing of the washing machine and noisy electronic device.

The paper is organized as follows. Section 2 presents description of the system used for the research. In Section 3 results of the experiments have been described. Section 4 contains conclusions and informations about future work.

2. System description

The experiments were performed using an acoustic camera system, consisted of acoustic and vision parts. Both of them provide digital signals to the PC unit (Fig. 1(a)).

The main element of the acoustic part are 48 microphones arranged into a planar, spiral array with six arms (Fig. 1(b)), according to Underbrink geometry [11]. The microphones coordinates were calculated by equations [7]:

$$r_{m,1} = r_0, \qquad m = 1, ..., N_a, \tag{1}$$

$$r_{m,n} = \sqrt{\frac{2n-3}{2Nm-3}} r_{max}, \qquad m = 1, ..., N_a, \qquad n = 2, ..., N_m, \tag{2}$$

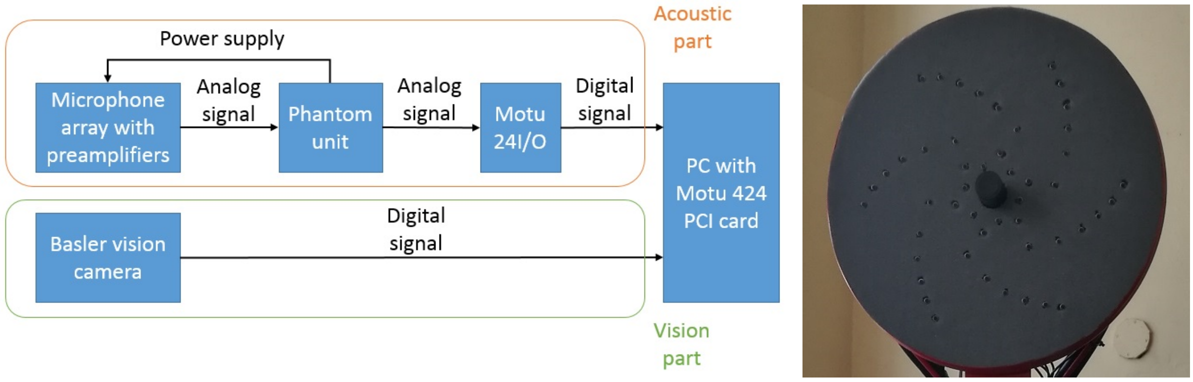
$$\theta_{m,n} = \frac{\ln(\frac{r_{m,n}}{r_0})}{\cot(\nu)} + \frac{m-1}{N_a} 2\pi, \qquad m = 1, ..., N_a, \qquad n = 1, ..., N_m, \tag{3}$$

where r_0 and r_{max} are minimum and maximum distances between center of the spiral and following microphones, N_a is number of spiral arms, N_m is number of microphones on a single spiral, ν is an angle of spiral and θ is an angle of microphone rotation around center of the spiral. The signals from the microphones are gained using preamplifiers and discretized by a Motu 24I/O DAC. The vision part is based on GigE Basler camera, with CCD sensor and 20 fps frame rate. It makes it possible to get refresh rate high enough to localize fast, non-stationary sound sources.

The acoustic data are processed and interpreted using MUSIC—frequency based, narrowband beamforming algorithm [3]. Next, the map of acoustic signals is created. Finally, this map is overlayed on the vision image for getting information about spatial position of the sound source. The main technical parameters of the acoustic camera system are presented in Tab. 1. The clarity of the acoustic map depends on frequency of sound and spatial resolution [5]:

$$R = \frac{d}{D} \lambda, \tag{4}$$

where R is spatial resolution, D is a diameter of the microphone array, d is a distance between acoustic camera and source of the sound and λ is an acoustic wavelength. The main disadvantage of the beamforming algorithms is dependency between spatial resolution and microphone array diameter. For localisation of the sources of low frequency sounds (below 1 kHz) it is necessary to expand size of acoustic camera, what results in decreased practical feasibility of the device. The idea to avoid such situation is using band-pass filter for selection of localised frequencies.



(a) (b)

Fig. 1. a) block diagram of the system; b) microphone array with a vision camera

Table 1

Acoustic camera technical informations.

Number of microphones	48
Diameter	0,31 m
Geometry	2D Underbrink array
Recommended frequency range	1,3 kHz to 11 kHz
Data acquisition unit	1x Motu 424 PCI, 2x Motu 24I/O
Vision camera	Basler acA1600-20gc
Microphone type	Electret

3. Results

The experiments were performed for several objects, in accordance to the following points:

1. Observation of the frequency spectrum of a background noise.
2. Selection of the frequency range and maximal amplitude of the noise.
3. Observation of the frequency spectrum of the acoustic signal, emitted by the object.
4. Selection of the preferred frequency range, without noise.
5. Change of the band-pass filter settings.
6. Localisation of the sound sources.

The acoustic signals were measured in almost full audible band (20 Hz to 20 kHz). During data processing, the frequencies from the preferred range were extracted and used for sound source localisation in the MUSIC algorithm. Amplitude of the signal is expressed by relative intensity, normalized to 0-1 range.

3.1. Electric motors

Firstly, the acoustic emissions of a damaged electric motor (Fig. 2(a)) and an undamaged electric motor (Fig. 2(c)) from the electromagnetic mill system [13] were compared. The experiment was performed in a small room, with the poor acoustic properties, but it had no visible influence on the results. The difference between frequency spectra (Fig. 2(b), 2(d)) is significant in the lower band (below 4 kHz), where the signal amplitude is stronger. There are also differences in the higher band (above 16 kHz), where some unusual signal components appear. The probable cause of the first motor fault is a slight curvature of the shaft.

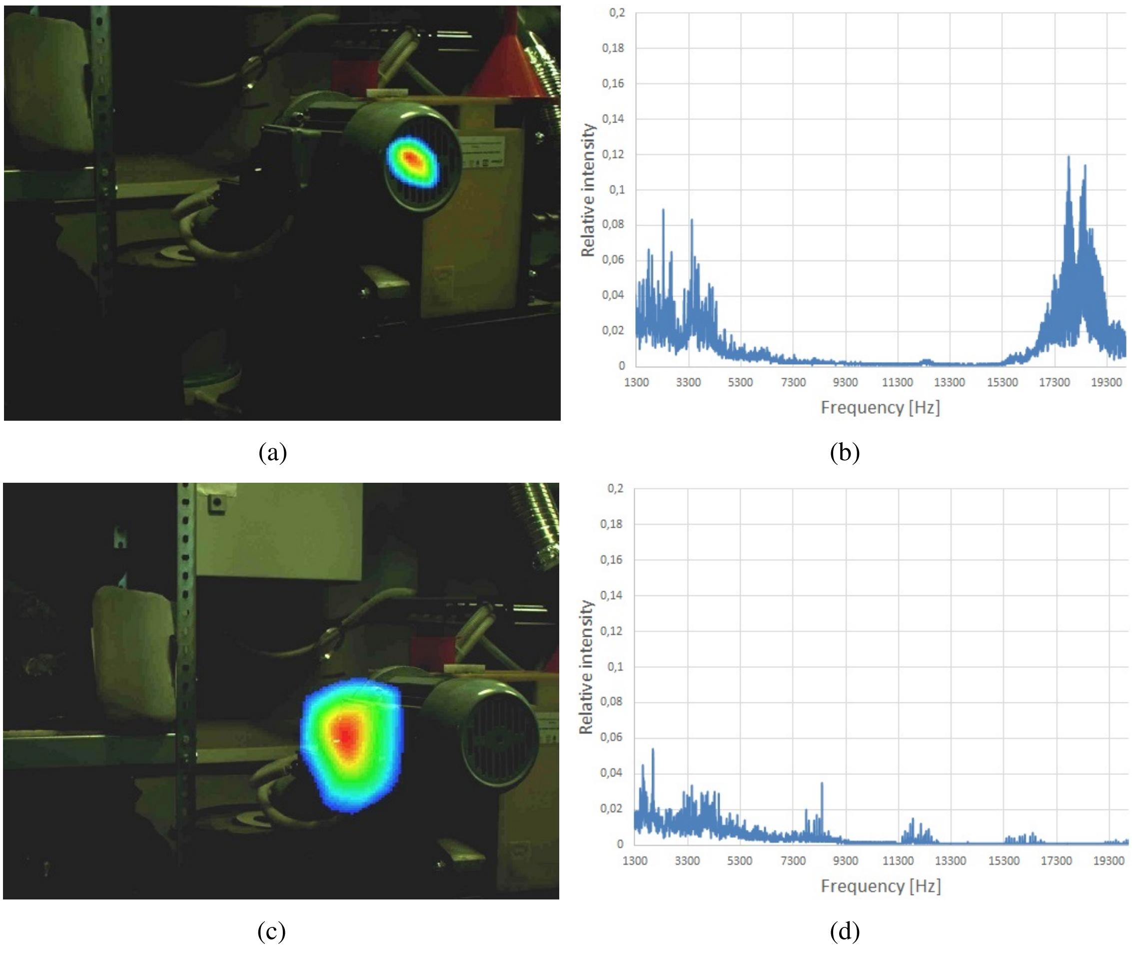
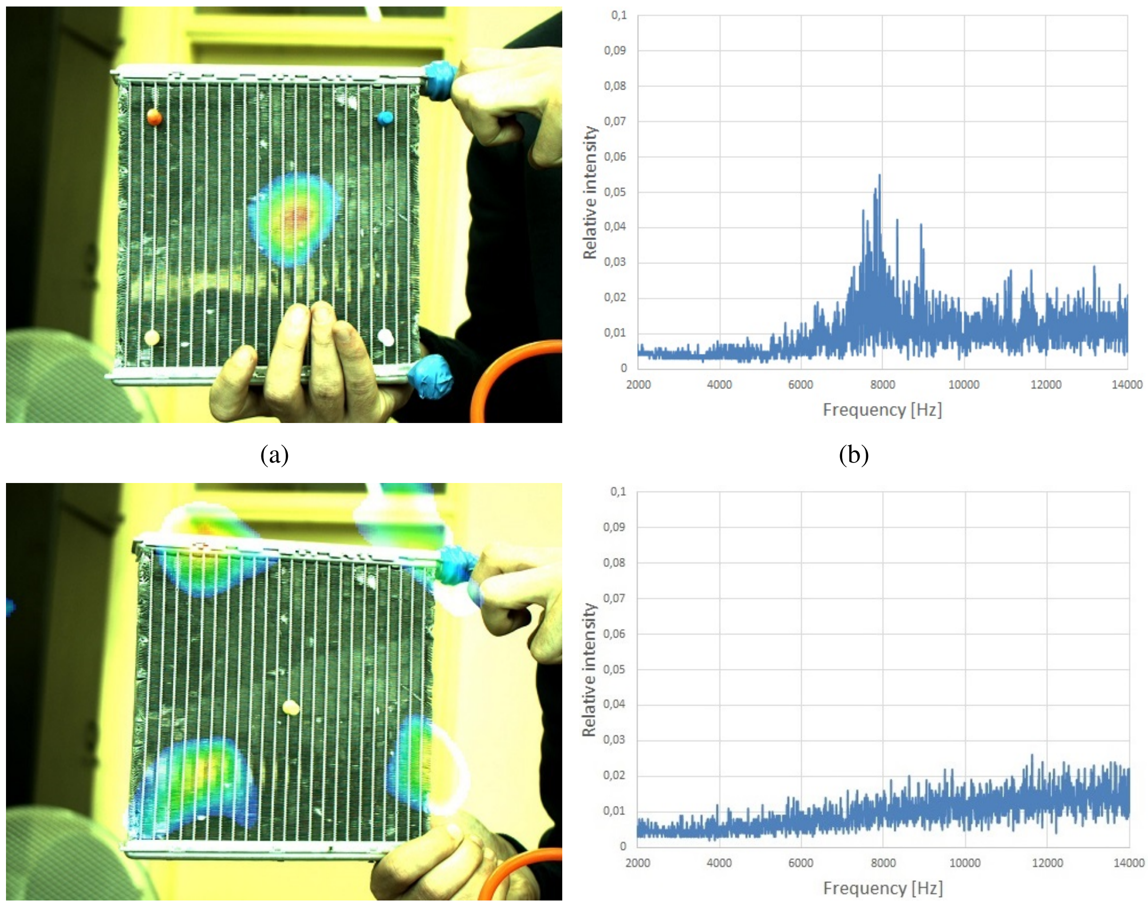


Fig. 2. a) final image for damaged motor; b) signal spectrum for damaged motor; c) final image for undamaged motor; d) signal spectrum for undamaged motor

3.2. Leaky cooler

The next analysed object was a cooler with punctures made with a pin. The two cases were considered: one hole in the centre (Fig. 3(a)) and one hole in each corner (Fig. 3(c)). The source of the acoustic signal was the air supplied from the compressor to the cooler and leaked through the holes. The difference in frequency spectra (Fig. 3(b), 3(d)) is caused by different air pressure in both of experiments. In the case of a single hole, the localisation is correct, but for the second situation some distortions on acoustic map are observed. It is due to a small leak on connection between cooler and compressor, which shifts visual positions of sound sources.



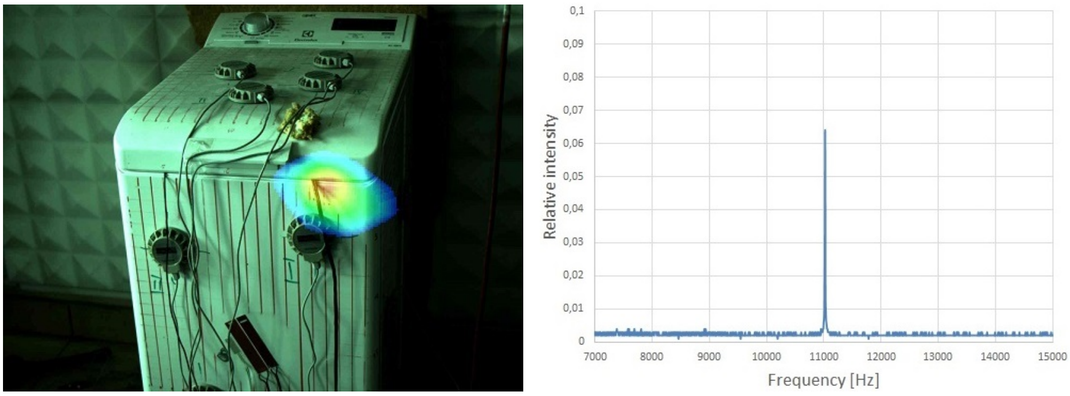
(a) (b)

(c) (d)

Fig. 3. a) final image for cooler with single hole; b) signal spectrum for cooler with single hole; c) final image for cooler with four holes; d) signal spectrum for cooler with four holes

3.3. Washing machine

During the washing machine experiment (Fig. 4(a)) some noise from several components in lower frequencies (below 500 Hz) appeared. Therefore, a high frequency (11 kHz) for tightness test was used (Fig. 4(b)).



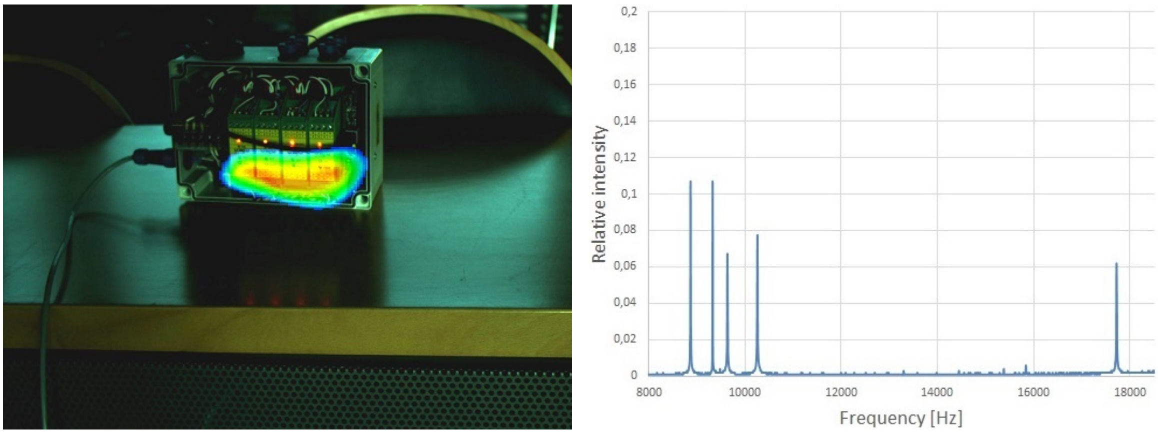
(a) (b)

Fig. 4. a) final image for washing machine; b) signal spectrum for washing machine

The source of sound was a loudspeaker placed inside a drum of the washing machine [14]. The acoustic camera was pointed at a spot, where the loudspeaker cable deformed the door gasket. Thus, an acoustic leak occurred, perceived as a source of noise.

3.4. Noisy electronic device

In electronic devices there are some components, which emit the annoying, high frequency sounds under the electromagnetic excitation, e.g. inductors in switched power converters. The other examples is the LVDT amplifiers and voltage converter used in semi-active suspension system [4]. Before experiment, it was assumed that the coil in voltage converter is the source of the sound. The results suggest that the noisy amplifiers were the reason of these problems (Fig. 5(a)) and frequencies of emitted sounds were high, which could be disturbing (Fig. 5(b)).

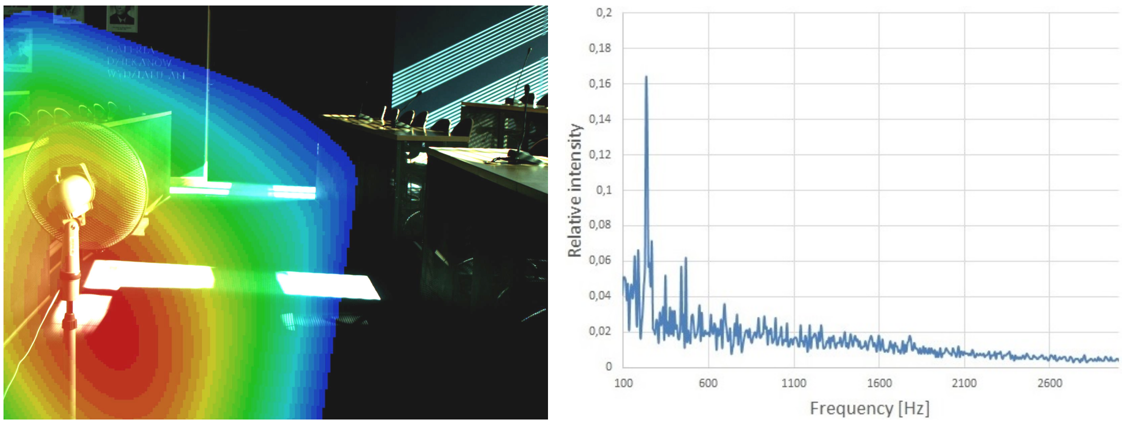


(a) (b)

Fig. 5. a) final image for electronic device; b) signal spectrum for electronic device

3.5. Floor-standing fan

The last experiment based on the floor-standing fan (Fig. 6(a)). In a comparison to the previous objects the band of emitted frequencies was lower. The dominant frequency was about 250 Hz (Fig. 6(b)).



(a) (b)

Fig. 6. a) final image for floor-standing fan; b) signal spectrum for floor-standing fan

Therefore, a size of the acoustic map of signal is bigger compared to the washing machine or the cooler cases. The final image is not clear and in consequence, the localisation of the sound source is less effective.

4. Conclusions

In this paper several tests of localisation of the undesirable sound sources are described. The experiments were based on several objects: electric motors, cooler, washing machine and noisy LVDT signal conditioner. In every case the sound sources were correctly marked. The obtained results show that acoustic camera could be an useful tool for non-destructive diagnostics. The examples of cooler and washing machine prove device precision in gas and acoustic leakage detection. The diameter of microphone array is sufficient for localisation of the high frequencies (above 1 kHz), but for the lower part of band, image from the acoustic camera is unclear. This situation is illustrated by an example of the floor-standing fan, where acoustic map has above half of the whole vision image size.

A commonly used method to increase the clarity of the acoustic map for low frequencies is the Near field Acoustical Holography (NAH), instead of beamforming algorithms, but only for sound source localisation in close distances. Therefore, in commercial acoustic cameras there are some constructions, in which both methods are implemented.

5. Acknowledgment

The research reported in this paper was partially supported by the Polish Ministry of Science and Higher Education funding for statutory activities of young researchers, grant no. BKM/508/RAU1/2017, and by the National Science Centre, Poland, decision no. DEC-2017/25/B/ST7/02236.

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