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LABORATORY MODEL OF ACOUSTIC CAMERA BASED ON DIRECT LOCALIZATION METHODS: CONCEPT, IMPLEMENTATION AND SOME EXPERIMENTAL RESULTS

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ABSTRACT

In previous BeBeC 2012 conference authors proposed direct localization method based on steered covariance matrix approach, as an innovative method which can be applied for acoustical mapping in acoustic camera. Meanwhile, the authors realized low cost laboratory model of acoustic camera, named it *LM-ERA*. It integrates hardware components such as microphone array, signal processing platform with multichannel signal acquisition daughter boards, video camera and PC computer. Application software with Graphical User Interface is developed in MATLAB. Concept and practical implementation of laboratory model of acoustic camera *LM-ERA* are shortly presented in the paper. Some experimental results of acoustical mapping in real indoor environment are also presented in the paper. In order to illustrate functionality and performances of the realized *LM-ERA* acoustic camera preliminary experimental results provided by the use *LM-ERA* acoustic camera are compared with results provided by Brüel & Kjær acoustic camera for the same signal scenario.

1 INTRODUCTION

Motivation for design and realization of laboratory model of acoustic camera is related to the Serbian national project of Ministry of Science and Technological Development TR 32026 called "*Integration and Harmonization of Sound Insulation in Buildings in the Context of Sustainable Housing*". In this project we tend to apply technical solutions of acoustic camera for development and verification of technical solutions for sound insulation in buildings. For those purposes we needed some kind of acoustic camera. As the authors best knowledge, almost all acoustic cameras available at market are delivered as laboratory instruments with application software in closed form and possible option to export file with acquired data for further off-line processing [1-5]. So our idea is to design and realize our own acoustic camera as open scalable platform in order to implement acoustical mapping based on direct localization method proposed by authors as innovative solution for acoustical mapping [6,7]. It is good option from the point of researching, development, implementation and testing of new algorithms for acoustical mapping. The idea is also, that measurement data acquired by the use of some other commercially available acoustic cameras can be imported and processed by the application software of our acoustic camera. Hardware components such as microphone array, signal processing platform with multichannel signal acquisition daughter boards, video camera and PC computer are integrated in hardware. Application software with Graphical User Interface is developed in MATLAB. At this moment it likes as laboratory model but it is open scalable platform and further improvements and developments towards prototype and possibly commercial product are possible.

Structure of the paper is the next. Brief review of acoustical mapping based on direct localization is shortly presented in section 2. Concept of laboratory model and practical implementation of hardware and software are shortly presented in the section 3. Some experimental results of acoustical mapping in real indoor environment provided by the use of realized laboratory model of acoustic camera *LM-ERA* are presented in the section 4.

2 BRIEF REVIEW OF THE ACOUSTIC MAPPING IN NEAR FIELD SIGNAL SCENARIO BASED ON DIRECT LOCALIZATION AND STEERED COVARINACE MATRIX APPROACH

Suppose near field acoustic multiple incident signal scenario with K acoustic sources at the unknown locations denoted by the set of vectors $\mathbf{r}_k \in \mathbb{R}^3; k=1,K$. Summary acoustic signal from K acoustic sources at the unknown locations denoted by the set of vectors $\mathbf{r}_k \in \mathbb{R}^3; k=1,K$ received by the microphone array with L microphones on the known locations denoted by the set of vectors $\mathbf{p}_l \in \mathbb{R}^3; l=1,L$ can be modeled discrete time domain in the next form [1]:

$$x_l(n\Delta t) = \sum_{k=1}^{K} b_l(\mathbf{r}_k) s_k^0(n\Delta t - \tau_l(\mathbf{r}_k)) + \eta_l(n\Delta t); n=1,N \tag{1}$$

where $b_l(\mathbf{r}_k)$ and $\tau_l(\mathbf{r}_k) = |\mathbf{p}_l - \mathbf{r}_k| / v$ denote attenuation and propagation time delay of the k-th signal, $s_k^{(0)}(.)$ denotes signal of the k-th acoustic source on its location, N denotes total number of signal samples and v denotes velocity of acoustic wave.

Steering preprocessing transformation in near-field signal scenario is performed in frequency domain in such a way:

$$\mathbf{x}_l^{st}(n\Delta T, \mathbf{r}) = \sum_{n=1}^{N} \mathbf{T}_l(\omega_n, \mathbf{r}) \mathbf{x}_l(\omega_n) e^{j\omega_k n\Delta t} \tag{2}$$

where $\mathbf{x}_l(\omega_n)$ denotes vector with spectral samples of the acoustic signal on the l-th microphone and vector $\mathbf{x}_l^{st}(n\Delta T, \mathbf{r}) \in C^{1xN}$ represents vector of the time samples on the l-th microphone in the array after the steering preprocessing transformation. Matrix $\mathbf{T}_l(\omega_n, \mathbf{r}) \in C^{LxL}$, which is so called steering matrix, is diagonal matrix with elements $b_l(\mathbf{r})^{-1} e^{j\omega_n \|\mathbf{p}_l - \mathbf{r}\|/v}$ on the main diagonal.

Furthermore, steered covariance matrix $\mathbf{R}^{st}(\mathbf{r}) \in C^{LxL}$, which is location dependent, can be estimated as:

$$\mathbf{R}^{st}(\mathbf{r}) = E\{\mathbf{x}^{st}(n\Delta T, \mathbf{r})\mathbf{x}^{st}(n\Delta T, \mathbf{r})^{H}\} \quad (3)$$

Steered-Bartlett estimator based on use of steered covariance matrix, can be defined as*:*

$$P_{y}^{st\_BART}(\mathbf{r}) = \mathbf{v}^{H}\mathbf{R}^{st}(\mathbf{r})\mathbf{v} \quad (4)$$

Steered-MUSIC estimator can be defined as [7]:

$$P_{y}^{st\_MUSIC}(\mathbf{r}) = \frac{1}{\mathbf{v}^{H}\mathbf{E}^{st}(\mathbf{r})\mathbf{E}^{st}(\mathbf{r})^{H}\mathbf{v}} \quad (5)$$

Vector $\mathbf{v}(\mathbf{r}) \in \mathbb{R}^{Lx1}$ in eq. 4. and 5. has a form:

$$\mathbf{v} = [1 \quad 1 \quad \ldots \quad 1]^{T} \in \mathbb{R}^{Lx1} \quad (6)$$

Matrix $\mathbf{E}^{st}(\mathbf{r})$ is the noise subspace matrix of the steered covariance matrix $\mathbf{R}^{st}(\mathbf{r})$.

3 CONCEPT AND PRACTICAL IMPLEMENTATION OF LABORATORY MODEL OF ACOUSTIC CAMERA *LM-ERA*

Block scheme of the laboratory model of acoustic camera *LM-ERA* is shown on the Fig.1. Main components of hardware platform of *LM-ERA* are microphone array with video camera, signal-processing board with multichannel acquisition daughter boards, and laptop computer. Microphone array is designed as planar array with four concentric circular arrays. Low cost commercially available Genius MIC-01C microphones are used in functional model of acoustic camera, but there is no limitation regarding geometry of microphone array and type of used microphones. Genius web camera *FaceCam 1005* is mounted in the center of microphone array. Multichannel signal acquisition is performed by DSK_AUDIO4 four-channel audio input/output acquisition card mounted as daughter board card on the Texas Instruments TMS320C6713 DSP Starter Kit (DSK). At this moment just one such acquisition card was available but up to four such acquisition card can be mounted on the same DSK platform forming 16-channe acquisition system. Application Programming Interface (API) of DSK_AUDIO4 is used to control of those cards from application software developed in MATLAB. By the use of API function it is possible to choose sampling frequency and programmable gains of input channels. DSK platform with just one DSK_AUDIO4 board is used at this moment just for four-channel signal acquisition and streaming to PC, but implementation of direct localization methods on signal processing boards for real-time acoustical mapping is possible in the future. Application software of laboratory model of acoustic camera LM-ERA is developed in MATLAB. It has object oriented graphical user interface, Fig. 2, with many functional pushbuttons and pop-keys, and four windows W1, W2, W3 and W4. Time samples of the signal from microphones are plotted on the W1 window. Amplitude spectrum and spectrogram of the signal from selected microphone are plotted on the W2 and W3 microphone, respectively. Results of acoustical mapping are plotted on the W4 window. Measurement data with all required parameters (microphone geometry, parameters of acquisitions, frames of images from camera etc) and results of acoustical mapping can be memorized in file, and used late for repeated processing

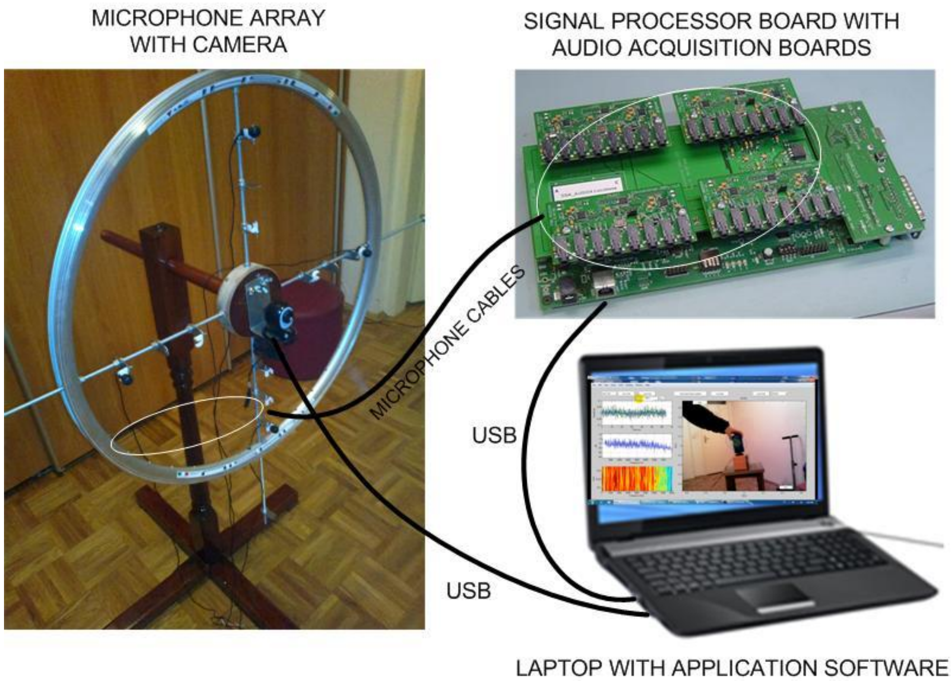

Fig.1. Block scheme of the laboratory model of acoustic camera *LM-ERA*

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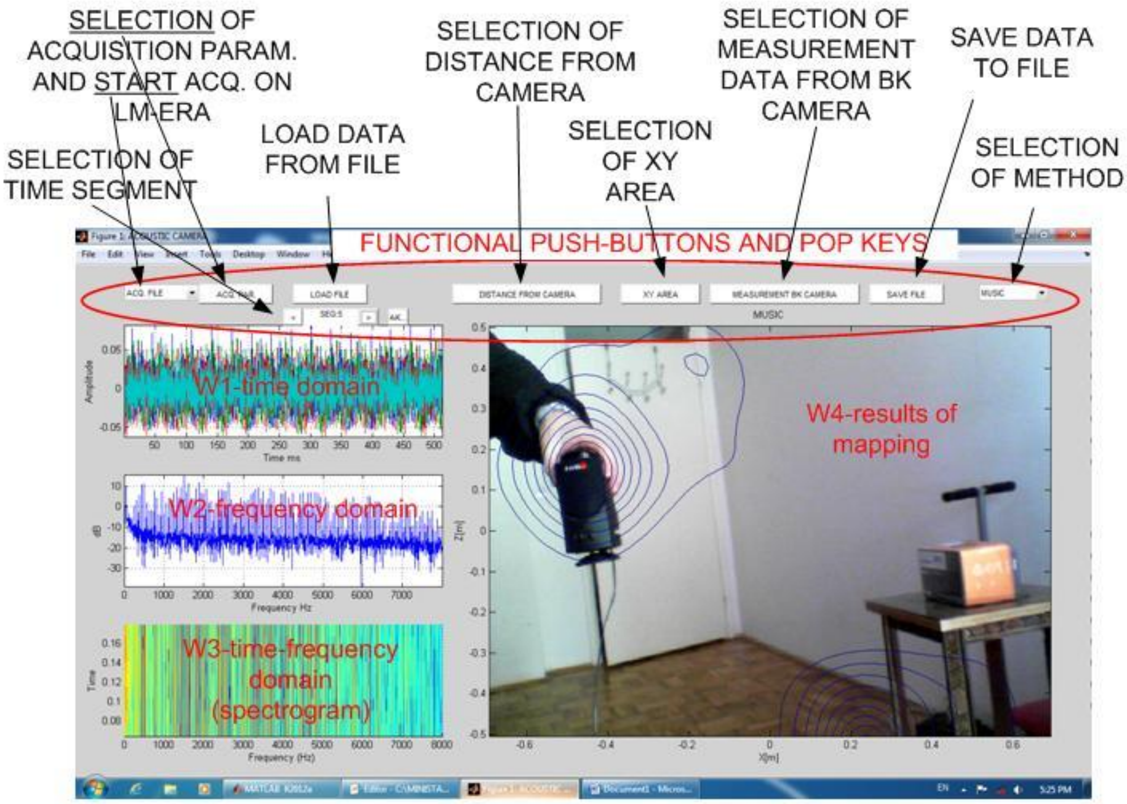

Fig.2. Graphical User Interface (GUI) of the *LM-ERA* acoustic camera

4 RESULTS OF EXPERIMENTAL VERIFICATION IN REAL INDOOR ENVIRONMENT

Results of acoustical mapping of the loudspeaker for two indoor scenarios, by the use of realized *LM-ERA* acoustic camera, are presented on the Fig. 3. and Fig.4., respectively. Acoustic equivalent of pseudo-noise sequence implemented in *UWB MIMO channel sounder* [10] is used in measurements as acoustic signal transmitted from loudspeaker. *Steered MUSIC* function is calculated on grid points in *x0y* plane for the value of *z* equal to the known (measured) distance of loudspeakers from the plane of microphones (1.5 m) and for time interval equal to 1024 signal samples (sampling frequency was 16ks/s). In both scenarios mapping is repeated for many signal frames which correspond to different positions of loudspeaker and results of localizations was always inside contour of the loudspeaker. Contour plot (level curves) of results of mapping is plotted for values [0 dB,-1 dB,…,-9 dB,-10 dB] of normalized values of *Pm*.

In the second measurement scenario, measurement setup with Brüel & Kjær acoustic camera is used, Fig. 5. The same data acquired by Brüel & Kjær acoustic camera are used both for acoustical mapping by the use of Brüel & Kjær acoustic camera and acoustical mapping by the use realized *LM-ERA* acoustic camera. In the second measurement scenario three signal scenarios are realized. Acoustic equivalent of pseudo-noise sequence implemented in *UWB MIMO* channel sounder was transmitted from first loudspeaker in the first scenario. Results of acoustical mapping by the use of realized *LM-ERA* acoustic camera and by the use of Brüel & Kjær acoustic camera are presented on the Fig. 5 and Fig 6., respectively. MLS sequence was transmitted from the second loudspeaker in the second signal scenario. Results of acoustical mapping of the second loudspeaker provided by the use of realized *LM-ERA* acoustic camera and by the use of Brüel & Kjær acoustic camera are presented on the Fig. 7 and Fig 8., respectively. In the third signal scenario both loudspeakers are active at same time. Results of acoustical mapping of the third signal scenario provided by the use of realized *LM-ERA* acoustic camera and by the use of Brüel & Kjær acoustic camera are presented on the Fig. 9 and Fig 10., respectively. Step size in contour plots in figures 6-10 was the same (1dB). Preliminary results show that results of acoustical mapping provided by *LM-ERA* acoustic camera are at least comparable with results provided by of Brüel & Kjær acoustic camera.

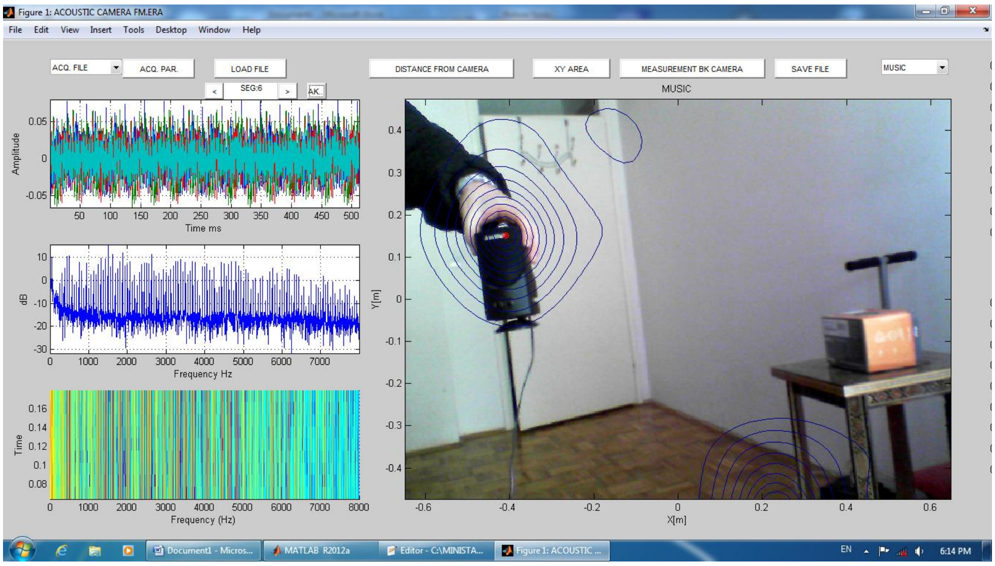

Fig.3. Results of acoustical mapping of the loudspeaker by the use of *LM-ERA* acoustic camera (first indoor scenario)

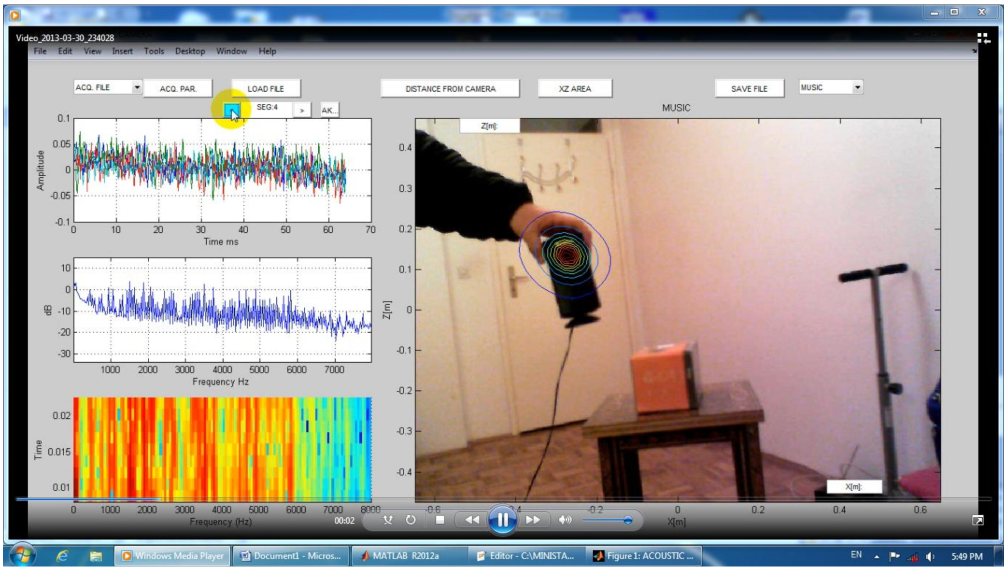

Fig.4 Results of acoustical mapping of the loudspeaker by the use of *LM-ERA* acoustic camera (second indoor scenario)

Fig.5 Measurement setup with Brüel & Kjær acoustic camera

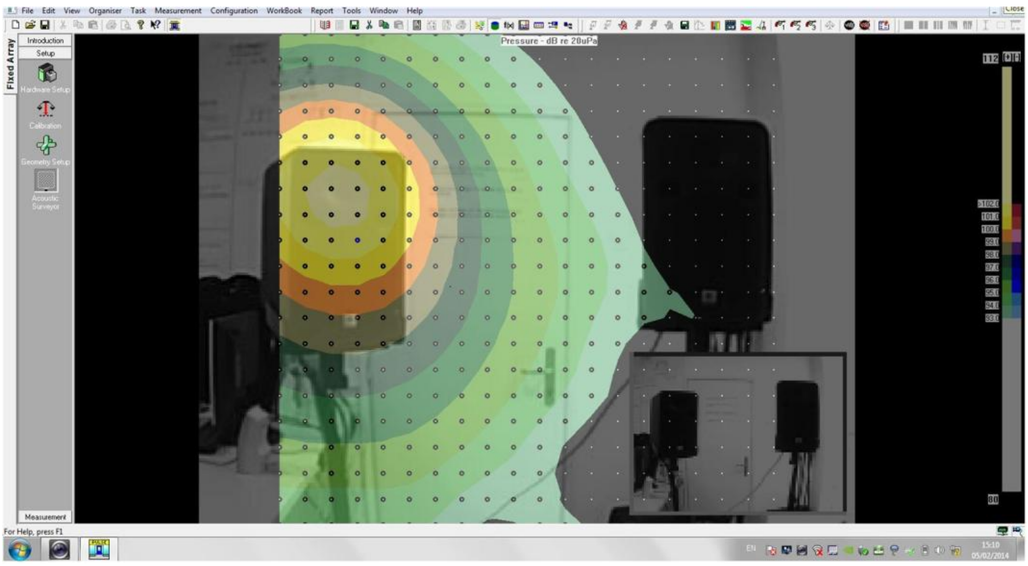

Fig.6. Results of acoustical mapping of the first active loudspeaker provided by Brüel & Kjær camera

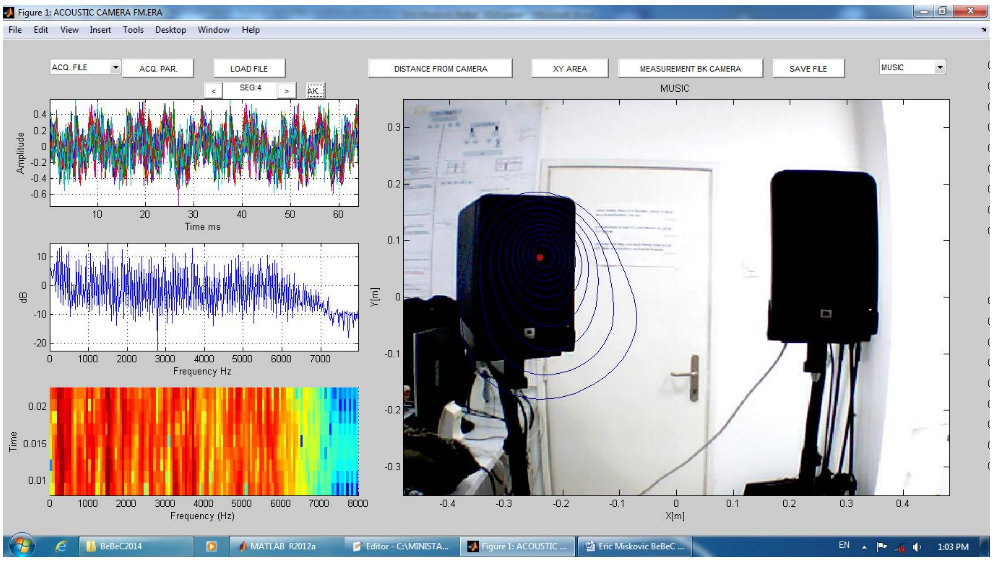

Fig.7. Results of acoustical mapping of the first active loudspeaker provided by *LM-ERA* camera based on measurement data acquired on Brüel & Kjær camera

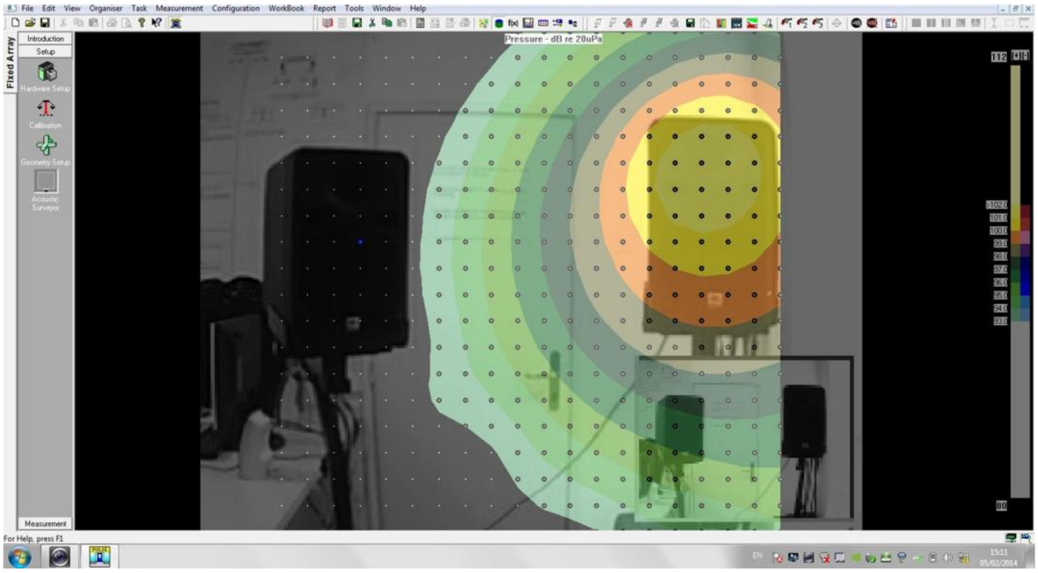

Fig.8. Results of acoustical mapping of the second active loudspeaker provided by Brüel & Kjær camera

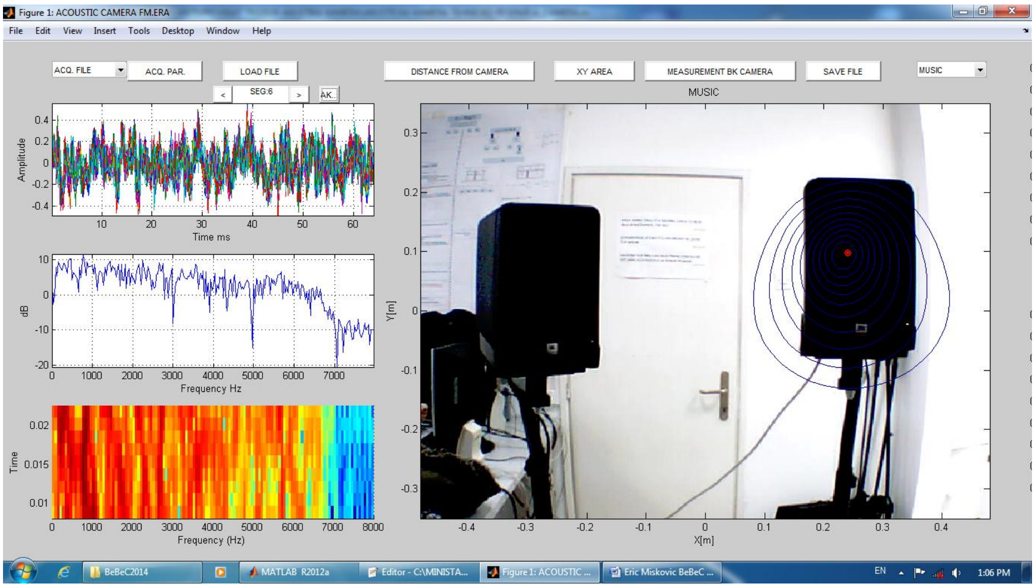

Fig.9. Results of acoustical mapping of the second active loudspeaker provided by *LM-ERA* camera based on measurement data acquired on Brüel & Kjær

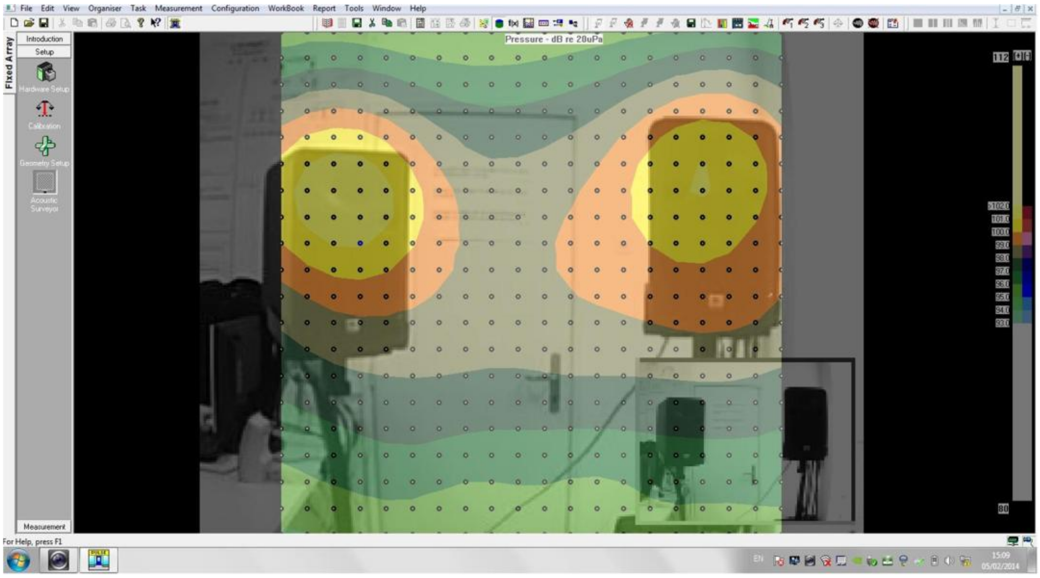

Fig.10. Results of acoustical mapping of the first and second active loudspeaker provided by Brüel & Kjær camera

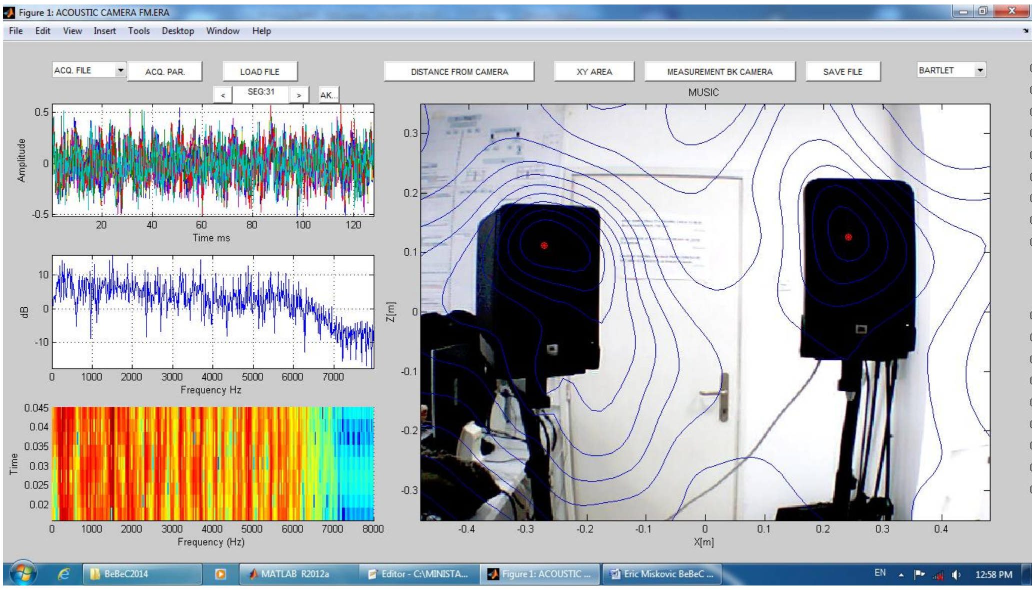

Fig.11. Results of acoustical mapping of the first and second active loudspeaker provided by *LM-ERA* camera based on measurement data acquired on Brüel & Kjær camera

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5 SUMARY AND CONCLUSION

Developed low cost laboratory model of acoustic camera based on direct localization method is shortly presented in this paper. Hardware components such as microphone array video camera, signal processing platform with multichannel signal acquisition daughter boards, and PC computer and application software with object oriented Graphical User Interface developed in MATLAB are integrated in realized laboratory model. Functionality and performance of the laboratory model are illustrated by some experimental results of indoor acoustical mapping and compared with results for the same signal scenario provided by Brüel & Kjær acoustic camera. As it can be seen, results of acoustical mapping provided by realized laboratory model for the same signal scenario are quite comparable with results provided by Brüel & Kjær acoustic camera.

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