Acoustical Imaging in Air by a Low-Cost System Working in Audio Band

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Abstract: In this paper, a system able to generate high resolution two-dimensional acoustic images of an aerial scene is described. Such a system works in the audio band and is composed of low-cost conventional acoustic and computation devices. Obtained images are of good quality despite the highly reverberant environment. Potential applications of the developed imaging system lie in robotic vision and remote measurement.

INTRODUCTION

Acoustical (sonar) imaging in air is very important in mobile robot vision for localization and navigation issues. Generally, a two-dimensional (2D) image of a scene (i.e., the top view of a scene) is composed by rotating a single ultrasonic sensor and acquiring many range measures related to several adjacent directions (1). Poor directionality limiting the accuracy in object spatial position determination affects the obtained map (2).

In this paper, a new acoustic imaging system that exploits an array of microphones to generate high resolution 2D acoustic images of an aerial scene is described. Such a system works in real-time, does not need to rotate, uses audio signals, and is composed of low-cost conventional acoustic and computation devices. The two major problems that were successfully faced are, first, microphones calibration and, second, the study of the best configuration in terms of waveform of the emitted pulse and microphone placements. Good quality images are generated by this system able to potentially improve performances of robotic vision algorithms.

SYSTEM ARCHITECTURE AND BEAMFORMING CONCEPT

The system is composed of a tweeter loudspeaker (Audix PH-3), an array of 8 little condenser microphones (Audix ML-10), a generation/acquisition board, and a personal computer (PC). Microphones were connected to the input channels of a National Instruments AT-MIO-16E-2 acquisition board able to sample simultaneously up to 8 signals using 12 bits per sample. The loudspeaker amplifier was connected to one of the two analog output channels of the same board. Such a board was inserted into a slot of a HP Vectra XU PC. The whole system is controlled by the National Instruments LabWindows/CVI 3.11 software. The procedure I have implemented to generate a 2D image is composed of the following steps: (i) an acoustic pulse is emitted by the loudspeaker toward the scene; (ii) the backscattered echoes impinging on the array sensors are acquired by the board and stored in the computer memory; (iii) a spatial processing of such data is performed by applying the beamforming (BF) approach; (iv) the signals in output from the beamformer are scan converted and (v) visualized on the PC screen as a 2D map in Cartesian coordinates. The BF goal is to estimate signals coming from a fixed steering direction, while attenuating those coming from other directions (3). It is a spatial filter that linearly combines the temporal signals spatially sampled by an array of sensors to generate a temporal output called beam signal. As the beam signal gives us information about the scene along the steering direction, by repeating the beam signal computation for a set of adjacent steering directions, one can obtain a 2D image of the whole scene (4). Therefore, echoes acquired once can be exploited to compute all the beam signals necessary to form an image. After fixing a steering direction, the beam pattern (BP) is a function that yields the attenuation with which BF transfers a received wave to the beam signal, for each incidence angle (3).

CALIBRATION AND BEAM PATTERN

By supposing that both emitter and microphones are punctiform and omnidirectional and knowing the exact position of each element, it is possible to measure relative microphone errors in terms of amplitude and phase. After many tests, it was possible to understand that our microphones are characterized by marked amplitude errors and negligible phase errors. Therefore, an amplitude correction coefficient (computed by minimizing the difference between the measured system BP and the expected one) was used for each microphone.
In a BF system that uses wide band signals, BP depends not only on the array geometry and carrier frequency, but also on the pulse envelope. The system BP was experimentally evaluated as a point spread function, i.e., by placing the loudspeaker in front of the array and measuring the intensity of the pulse present in the beam signal for any steering direction. The expected BP has been computed as suggested in (5). Figure 1a shows the good agreement between the measured and expected BPs when a 2 kHz pulse with a 3 ms gaussian envelope is emitted and the microphone spacing is 5 cm. Little differences between the two BPs are due to: (i) phase errors, (ii) discrepancies between the desired and emitted pulse waveforms, (iii) environmental reverberation.

RESULTS AND COMPARISONS

After many experiments, the following set-up was fixed to generate high resolution 2D images: array spacing 15 cm, carrier frequency 12 kHz, pulse duration 0.12 ms, gaussian pulse envelope, channel sampling frequency 40 kHz. 121 beam signals were computed by a “delay & sum” BF with dynamic focusing and time-varying gains (4,6) to cover an angular extension of 60° and a range from 0.5 m to 2 m. Figure 1b shows the BP due to this set-up. The obtained lateral resolution is less than 1.5° and range accuracy is less than 2 cm, whereas in conventional ultrasonic sensors the angular resolution is not better than about 10° and range accuracy is not better than 6 cm. Figure 1c shows the obtained image of a scene composed of a metallic cylinder 1 m far from the array and a rough plastic square with a 30 cm side that is 1.3 m far from the array. Figure 1d shows a photograph of such a scene.

FIGURE 1. (a) Agreement between expected (dotted line) and measured (solid line) BPs. (b) BP of the described imaging system. (c) Image obtained by the described acoustic system and (d) photographic picture of the imaged scene.

REFERENCES