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Advanced Directional Audio System Using Optimized Ultrasound Technology with Environment Compensation

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Abstract: This paper presents the design of an advanced directional audio system using ultrasonic modulation technology with environmental compensation. The system employs a DSP controller, ultrasonic transducer array, and power amplification stage to produce a highly directional sound beam. Temperature and humidity sensors are incorporated to compensate environmental variations affecting ultrasonic propagation. The proposed architecture improves sound clarity, beam directivity, and reduces distortion.

I. INTRODUCTION

Sound in conventional audio systems propagates in all directions, which often leads to unwanted noise, sound interference, and lack of privacy in public environments. In places such as museums, libraries, exhibitions, and advertising displays, it is desirable to deliver sound only to a specific listener or a limited area without disturbing the surrounding environment. A unidirectional sound system, also known as a directional audio system, addresses this challenge by focusing sound waves into a narrow beam so that only people located within that beam can hear the audio clearly. Directional sound technology commonly uses ultrasonic carrier waves to transmit audio signals. The audible sound is modulated onto a high-frequency ultrasonic signal, typically around 40 kHz, which is beyond the range of human hearing. When this ultrasonic signal travels through air, nonlinear interactions in the medium cause the demodulation of the signal, thereby reconstructing the original audible sound only along the direction of propagation. This phenomenon enables highly focused sound transmission, similar to how a flashlight directs light in a narrow beam.

The proposed unidirectional sound system employs a combination of digital signal processing and ultrasonic transducer arrays to achieve directional sound projection. The audio signal from the source is first converted into digital form using an Analog-to-Digital Converter (ADC). A processing unit then modulates the signal, which is subsequently converted back into an analog signal using a Digital-to-Analog Converter (DAC). The signal is amplified using a high-power amplifier and transmitted through a 7×7 ultrasonic transducer array, producing a highly focused sound beam.

Such systems have significant applications in targeted advertising, assistive listening devices, museum exhibits, security systems, and personal audio zones. By directing sound precisely toward a listener, the system reduces noise pollution and enhances privacy while improving the overall listening experience. The development of compact ultrasonic transducers and advanced digital processing units has made it possible to design efficient and cost-effective directional sound systems for practical applications.

II. RELATED WORKS

Directional sound technology has gained considerable attention in recent years due to its ability to focus audio into a narrow beam without disturbing the surrounding environment. Several researchers have explored different techniques to generate and control directional sound using ultrasonic transducers and parametric acoustic arrays.One of the earliest studies in this field was conducted by Westervelt, who introduced the concept of the parametric acoustic array. This technique uses high-frequency ultrasonic waves to carry audio signals, which are demodulated in the air due to nonlinear acoustic effects. This principle forms the foundation for most modern directional sound systems.

Later, researchers improved this concept by using arrays of ultrasonic transducers to increase the directivity and efficiency of sound projection. Studies showed that arranging multiple ultrasonic emitters in an array configuration can significantly enhance beam focusing and increase the effective transmission distance. Parametric loudspeaker systems based on these arrays were developed for applications such as museum audio guides, targeted advertising, and private listening zones.

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Another significant development was the integration of digital signal processing techniques to improve sound quality and reduce distortion. Researchers implemented modulation techniques and signal conditioning circuits to enhance the clarity of the reconstructed audible sound. The use of microcontrollers and digital processors has enabled more precise control of modulation, amplification, and signal transmission. Commercial implementations of directional audio technology have also been introduced by companies such as Holosonics and Panphonics. Their systems use ultrasonic transducer arrays to create highly focused sound beams used in retail displays, interactive exhibits, and public information systems.

Despite these advancements, challenges such as limited sound intensity, distortion, and power consumption still remain. Recent research therefore focuses on improving modulation methods, amplifier efficiency, and transducer array design to enhance performance. The proposed system contributes to this research area by implementing a digitally controlled ultrasonic directional sound system using a transducer array and high-power amplification to achieve effective unidirectional sound projection.

III. WORKING PRINCIPLE

The unidirectional sound system operates based on the principle of ultrasonic directional audio transmission. In this technique, an audible audio signal is transmitted using high-frequency ultrasonic waves that are beyond the range of human hearing. When these ultrasonic waves propagate through air, nonlinear acoustic effects cause the signal to demodulate naturally, reconstructing the original audible sound only along the direction of propagation. This allows the sound to be focused into a narrow beam.

The system begins with an audio source, which provides the input sound signal. This signal is first converted into digital form using an Analog-to-Digital Converter (ADC). The digital signal is then processed by a controller, where modulation is performed to combine the audio signal with a high-frequency ultrasonic carrier signal.

After modulation, the digital signal is converted back into an analog signal using a Digital-to-Analog Converter (DAC). The resulting analog signal is then amplified using a high-power amplifier to achieve sufficient signal strength for ultrasonic transmission.

The amplified signal is supplied to a 7×7 ultrasonic transducer array, which converts the electrical signal into ultrasonic acoustic waves. Because ultrasonic waves have very short wavelengths, they can be focused into a highly directional beam. As the ultrasonic beam travels through the air, nonlinear interactions within the medium cause the modulated signal to self-demodulate, producing the original audible sound.

As a result, the sound is heard clearly only along the direction of the ultrasonic beam while people outside this beam experience little or no sound. This directional property makes the system suitable for applications such as targeted audio communication, museum exhibits, advertising displays, and private listening zones.

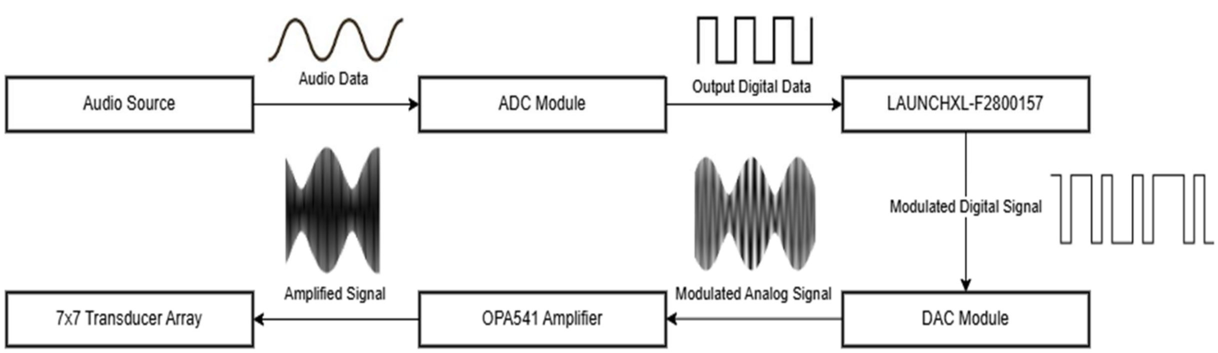

Fig.1 Block diagram of directional audio system

IV. DESIGN AND IMPLEMENTATION

The design of the unidirectional sound system focuses on generating and transmitting directional audio using ultrasonic carrier waves and an array of ultrasonic transducers. The system is developed using a combination of digital signal processing, amplification, and ultrasonic transmission techniques.

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A. System Design

The overall system consists of an audio input stage, signal processing unit, modulation stage, amplification stage, and ultrasonic transmission unit. The audio signal from the source is first converted into digital form using an Analog-to-Digital Converter (ADC). The digital signal is then processed by a microcontroller, where modulation with an ultrasonic carrier signal is performed.

The processed digital signal is converted back into an analog signal using a Digital-to-Analog Converter (DAC). This analog signal is then amplified using a high-power amplifier to drive the ultrasonic transducer array. The transducers convert the electrical signal into ultrasonic acoustic waves that propagate in a narrow beam.

B. Hardware Components

The implementation of the system involves several hardware components working together to achieve directional sound transmission.

1) Microcontroller – The system uses the LAUNCHXL-F2800157 development board for signal processing and modulation. It controls the ADC and DAC operations and performs the necessary modulation for ultrasonic transmission.
2) Data Acquisition Board – The AD9280 AD9708 Data Acquisition Development Board is used to perform high-speed analog-to-digital and digital-to-analog conversion of the audio signal.
3) Power Amplifier – A high-power operational amplifier, OPA541, is used to amplify the modulated signal before it is supplied to the ultrasonic transducers.
4) Ultrasonic Transducer Array – A 7×7 ultrasonic transmitter array operating at 40 kHz is used to generate the directional ultrasonic beam. The array arrangement improves the directivity and increases the effective sound projection distance.
5) Power Supply Unit – An AC-to-DC power supply module is used to provide stable voltage to the controller, amplifier, and transducer array.

C. Implementation Process

The implementation begins by capturing the audio signal through the input stage and converting it into digital form. The microcontroller processes the signal and performs ultrasonic modulation. The DAC converts the processed digital signal back to analog form, which is then amplified using the power amplifier.

The amplified signal is applied to the ultrasonic transducer array, which emits ultrasonic waves into the air. Due to the parametric acoustic effect, the ultrasonic waves demodulate during propagation and reproduce the original audio signal in a focused direction.

Through this design and implementation, the system is capable of producing highly directional sound, allowing audio to be heard only within a specific area while minimizing noise in the surrounding environment.

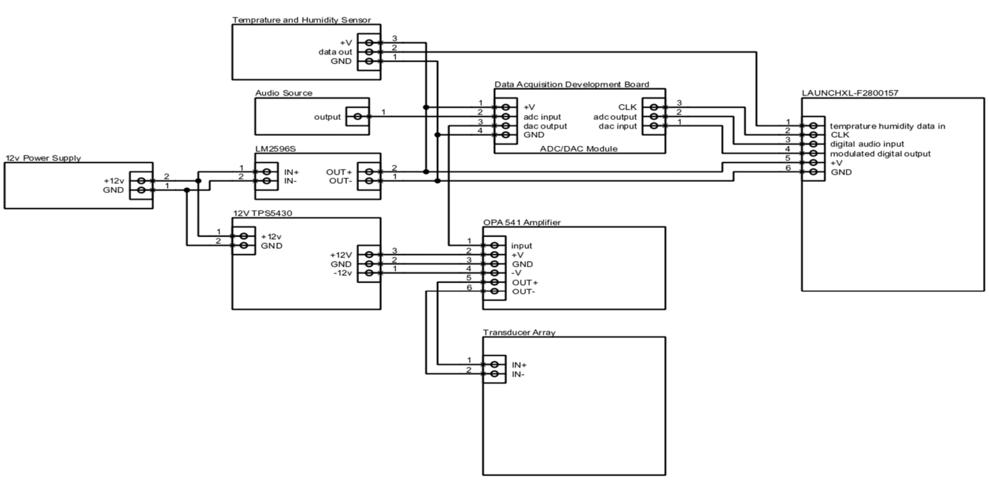
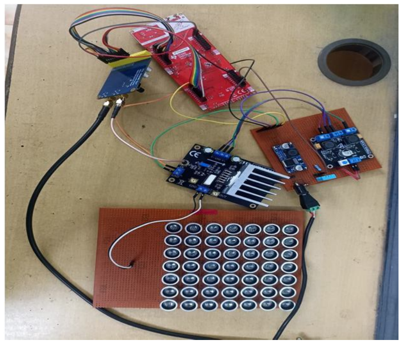


Fig.2 Circuit diagram of directional audio system

V. HARDWARE IMPLEMENTATION

The hardware implementation includes LAUNCHXL-F2800157 DSP board, OPA541 power amplifier module, ADC and DAC modules, ultrasonic transducers operating at 40 kHz, and temperature and humidity sensors. These components are integrated on a PCB with proper power supply and interconnection circuitry.



Fig,3 Hardware Implementation

VI. RESULTS

The unidirectional sound system was designed and implemented using an ultrasonic transducer array and digital signal processing techniques. The system was tested to evaluate its ability to transmit sound in a focused direction while minimizing sound leakage to surrounding areas.

During experimentation, the audio input signal was successfully modulated with the ultrasonic carrier and transmitted through the 7×7 ultrasonic transducer array. The transducers generated ultrasonic waves that propagated in a narrow beam. As the ultrasonic waves travelled through air, the nonlinear interaction of the medium caused self-demodulation, reconstructing the original audible sound.

The experimental results showed that the sound was clearly audible along the direction of the ultrasonic beam while remaining significantly weaker outside the targeted area. This confirms the effectiveness of the directional audio principle used in the system. The use of multiple ultrasonic transducers arranged in an array improved the beam directivity and increased the effective transmission distance.

The power amplifier stage also played an important role in enhancing the strength of the ultrasonic signal, enabling better sound projection. The digital signal processing performed by the controller ensured proper modulation and stable operation of the system.

Overall, the implemented system successfully demonstrated the capability of producing directional sound with reduced noise interference in surrounding regions. These results indicate that the proposed system can be effectively used in applications where targeted audio delivery is required.

VII. CONCLUSION

In this work, a unidirectional sound system based on ultrasonic directional audio technology was designed and implemented. The system utilizes ultrasonic carrier waves, digital signal processing, and an array of ultrasonic transducers to generate a highly focused sound beam.

The audio signal is processed through ADC and DAC modules and modulated with an ultrasonic carrier before being amplified and transmitted through the transducer array. Due to the nonlinear properties of air, the ultrasonic signal undergoes self-demodulation, reproducing the audible sound only along the direction of the beam.

Experimental results confirmed that the system can successfully deliver sound in a specific direction while minimizing disturbance to nearby areas. This directional property makes the system suitable for applications such as targeted advertising, museum exhibits, assistive listening systems, and private audio zones.

Future improvements can focus on increasing transmission distance, improving sound clarity, and optimizing the transducer array design to further enhance the performance of the system.

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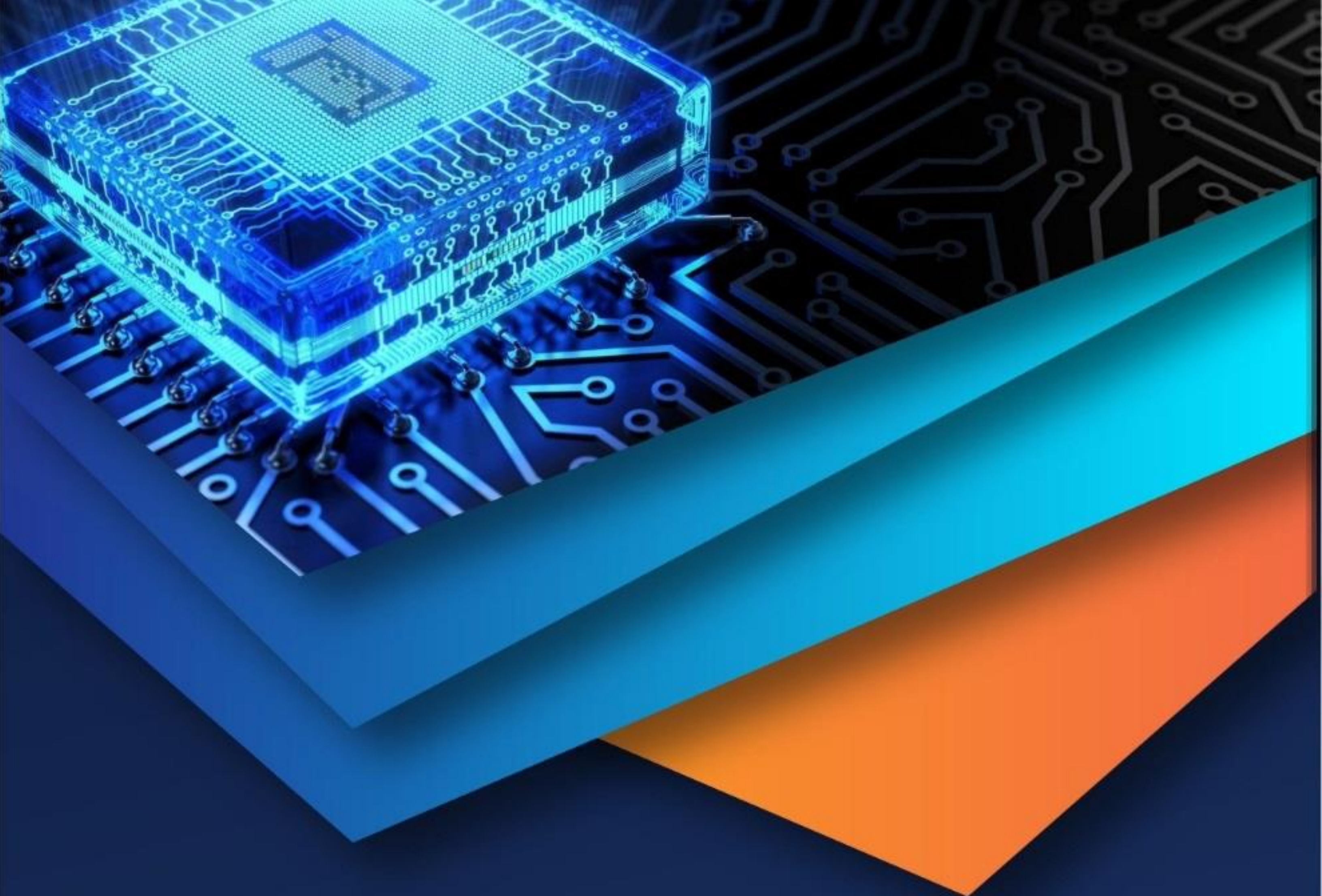

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