

Literature Review on Acoustic Waves and Personal Acoustic Spaces

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Introduction

The concept of wireless transmission has been a revolutionary idea for nearly 100 years. Namely, RADAR technology leverages the power of electromagnetic waves at a very low wavelength (radio) to measure distance and velocity of moving objects [7]. However, generating electromagnetic waves at a high frequency is power intensive [8]. To its counterpart, acoustic wave propagation is seen as a low-powered means for communication and sensing applications [3].

Such technology has significant potential in biosensing and physical imaging [2] as they consume less energy than legacy sonar technology due to its reduced transceiver arrays [3]. Large transceiver arrays are disadvantageous as they require multiple sets of expensive hardware to propagate waves and read incoming signals accurately [6]. In some applications, many use a thin, often subwavelength, material designed to offset the phase of an acoustic wave called a metasurface [9]. This is desirable, namely in ultra-low-powered acoustics, as metasurfaces diversify the signals and increase the sensing resolution when propagated back.

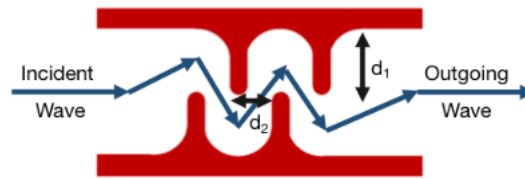
Our lab focuses, not on imaging with acoustic signals, but more so on personal acoustic spaces. Such spaces are ones where different users can get an acoustic zone in which only one desired signal is heard. How we can achieve a perfect personal acoustic space can be sought after by manipulating the waves' phase for either constructive or destructive interference in a targeted direction. Current solutions to this are lacking; a quick google search will indicate that common acoustic spaces are bedrooms or telephone booths which leak significant ambient noise. The company *Noveto* has come out with their i3DS™ speaker which attempts to create a personal acoustic space by only propagating signals to a user's ear [10]. There is, however, still some faint overshoot to others across a table. Our research aims to reduce the leaked noise ejected from an acoustic space and create one that completely encloses a user with their desired sound.

Background and Significance

The propagation of acoustic waves can be manipulated to obtain unique properties for individual channels by passing them from the source, such as a speaker, through a metasurface [4]. This is advantageous as we can increase the diversity of such signals by changing their individual phases across a thin cell structure, a metasurface. Figure 1 from *Adaptive metasurface-based acoustic imaging using joint optimization* illustrates the cross section of one cell in a metasurface where parameters such as “d1” and “d2” dictate how drastically a phase shift will occur

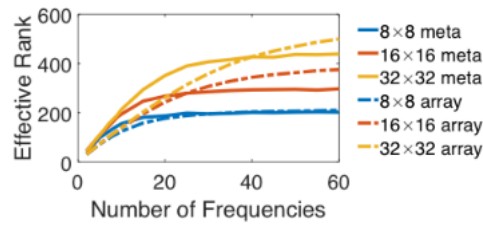
[3]; these cell structures are periodic in nature and adhere to the concept of a Helmholtz Resonator [11]. In short, a Helmholtz Resonator is a cell that absorbs incident sound waves and therefore gets excited leading to pressure fluctuations causing a resonant frequency to occur (what parameters “ d_1 ” and “ d_2 ” dictate). This resonance interferes with the incident waves to produce a desired phase shift on the outgoing signal.

Having a diverse array of signals coming off a metasurface can be advantageous in sensing applications as waves that are reflected can be discerned and pinpointed to a specific location; this could increase the image resolution in applications involving acoustic imaging [6]. Figure 2 illustrates how metasurfaces of various sizes can create many different signals.



[3]

Figure 1. Cross section of one metasurface cell illustrating width and height parameters.



[3]

Figure 2. Degrees of freedom in metasurface arrays

However, trends in Figure 2 also show that as the metasurface scales in size, the diversity in the audio signals tends to plateau. In comparison, when the transceiver array grows in number, the “Effective Rank” or image quality increases. Therefore, the accuracy of current audio imaging techniques via a metasurface decreases as the desired image gets larger. Nonetheless, metasurfaces still consume no energy compared to transceiver arrays which require expensive hardware and valuable real estate space on targeted applications; as a result, they are an excellent alternative to applications with constrained resources.

Many have attempted to address this concern of metasurfaces. In one method, namely *SPiDR: Ultra-low-power Acoustic Spatial Sensing for Micro-robot Navigation*, researchers abstract the concept of a 2D metasurface

into a 3D stencil (Figure 3) that channelizes the signals across various internal tubes of different lengths. In *Adaptive Metasurface-Based Acoustic Imaging using Joint Optimization* however, researchers utilize metasurfaces, despite their inability to scale largely, in conjunction with optimization algorithms that take the measured frequencies and manipulate the linear inverse equations that back them to have a better inference of what the image pixel values should be [3]. This however increases the overall energy cost due to the computations required in the optimization algorithms.

The use of metasurfaces has only been in part to understanding more about the region of space where direct acoustic energy is perceived [3]. This is known as the near-field in an acoustic space; metasurfaces contribute to this by creating scattering patterns off outgoing signals resulting in constructive interference [5]. Ultimately, the goal of our research is to create better personal acoustic space wherein it will leverage a metasurface to direct acoustic signals towards a desired path without leaking noise.

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