Project Proposal Title	Ultrasound Field Reconstruction Using Tomographic Schlieren Imaging
Name of School	San Diego State University
SPS Chapter Number	6388
Total Amount Requested	$2,000

Abstract

San Diego State University's SPS chapter introduces a tomographic Schlieren imaging technique to visualize 3D sound fields. A Schlieren imaging system's LED is synched with a 40kHz sound wave, producing 2D projections of the wave from multiple angles, which are combined to reconstruct the sound field's 3D shape.

Proposal Statement

Overview of Proposed Project

Ultrasound is a non-invasive imaging technique that is commonly used in the medical field for capturing real time images of internal organs. Measurement of the ultrasound field is required for the calibration of these instruments, this is crucial for the patients safety. Acousto- optical techniques, namely Schlieren imaging, are existing methods to visualize sound and pressure fields.

While Schlieren photography captures clear, 2D images of the sound field, viewing wave patterns through 2D projections can be limiting. Important features of a sound field characterization, such as the fields depth or x,y,z locations of high and low-pressure regions are lost. A tomographic approach is introduced. Slight rotation of the sound field allows for the schlieren set-up to capture images of the sound field at different angles. Careful reconstruction of these images results in a 3D characterization of the sound field.

This project is committed to the Society of Physics Students mission to advance the physical sciences and to transform students into contributing members of their professional communities. This study is open to physics enthusiasts of all backgrounds. Project members will gain the technical and soft skills necessary to conduct successful physics research. Along with developing technical methods and techniques, participating students will also be required to present their work at group meetings, academic conferences, and community outreach events.

Background for Proposed Project

An RGB Schlieren imaging technique has been developed from work that was previously supported by the SPS Chapter Research Award. An RGB LED is stroboscopically synched with a sound wave with a frequency of 40 kHz. The red, green, and blue channels are pulsed at ⅓ of the waves duty cycle while also having a slight delay.

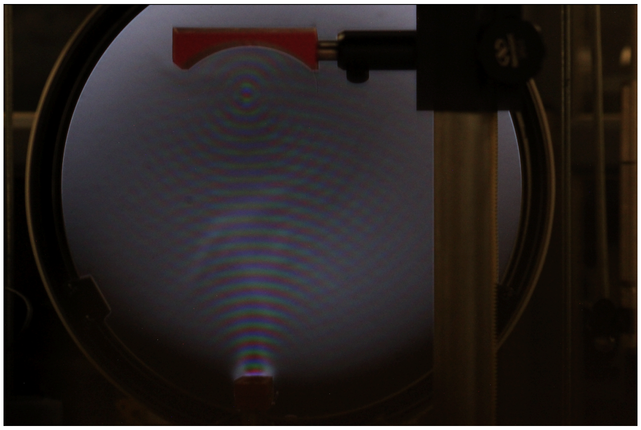

Fig.1. Ultrasound wave propagating vertically and bouncing off a curved reflector.

As the sound wave propagates over time, the pulsed LED captures the wave's alternating regions of high and low air pressure at specific moments in time, first red then green then blue. This technique is particularly useful for denoting the sound waves speed and direction of propagation.

RGB Schlieren photography has proven to be a powerful tool for imaging sound fields in two dimensions. This work aims to characterize a sound field in three dimensions using tomographic Schlieren imaging. The study of reconstructing an ultrasound field in 3D using a tomographic Schlieren imaging approach is a relatively young field. Our technique of pulsing the RGB LED will be incredibly useful for analyzing and characterizing a sound field's behavior in three dimensions.

Expected Results

Our team is working towards two main objectives:

1. Generate more complex sound fields with a 10x10 array using an FPGA based array of phased ultrasonic transducers.
2. Realize the reconstruction of this 3D sound field

Part 1 is well underway. We have been able to generate and image ultrasound from multiple sources, demonstrating interference, standing waves, reflection, etc. Recent progress using an Arduino to drive multiple transducers simultaneously has been demonstrated, controlling both their amplitude and phase. The next major steps are to broaden this horizon to a complete array of transducers (10x10) and be able to control each individually. This will require a new FPGA approach, and is well within the capabilities of the team.

Part 2 represents a significant leap and is the major expected outcome from this project. We envision being able to first optimize the Schlieren image from complicated wave fields, and then rotate the source. Collection of 2D Schlieren data from a series of angles will allow for the recombination of these images into one 3D visualization.. A unique expected outcome from this project is being able to see local traps in the sound field that might not be otherwise visible with a 2D image.

Expected deliverables: 1-2 student presentations on campus, 1-2 student presentations at conferences, and 1-2 publications.

Description of Proposed Research - Methods, Design, and Procedures

Experiment Set-up

The experiment consists of an LED light source, a test area for the sound field, a parabolic mirror, a razor blade on translation stage, and a DSLR camera. This is a simple reflective 4f system occupying 2m of table length, with all the elements collinearly aligned.. Light from the LED propagates through the sound field, generated from a phased array of transducers, mounted to a rotational stage and placed approximately 6 inches from the mirror in the test area. The light propagates through the sound field and reflects off the parabolic mirror, passes back through the sound field a second time and enters the camera. A razor blade is adjusted to impinge roughly half of the light at the focal spot of the mirror, which gives the Schlieren imaging effect.

Experiment Execution

Several valuable techniques will be used in the execution of the experiment. The first is the driving of the RGB LED. This requires a stable electronic source that is capable of generating three separate 1 microsecond pulses at a 40kHz repetition rate, each separated by about 8 microseconds. The second is the alignment of the red, green and blue rays. While the LED has a diffuse housing, the uniform mixing of the RGB is not quite achieved. An integration sphere and aperture are used to generate a truly white point source. This point source should be placed 2f away from the parabolic mirror (which in our case has f = 1m). The reflected spot can be adjusted to return slightly higher, allowing it to skim over the top of the LED assembly. The focused spot can be seen on a card (with the lab lights off), which indicates the ideal position of the razor blade's edge. With a translation stage, you can adjust the razor blade's vertical position. The camera is placed immediately behind the razor blade, and zoomed in and focused on the test area. We found it very useful to have an HDMI output from the DSLR with a computer monitor for easy viewing. The transducers are placed in the test area and turned on. By careful adjustment of the razor blade, a good contrast image of the ultrasound field is obtained. Once optimized for a particular angle, we will rotate the sound field to demonstrate that the 2D images are nearly identical for all angles with our plane wave field. Once satisfied with the system's functionality, we will turn to more complicated sound fields.

Data Analysis

Once the transducer array is operational, we will turn to the task of predicting what the 3D sound field will look like, based on the Huygens-Fresnel wavelet theory approach. In this scheme (which we have tackled numerically before with optical beams [1]), each transducer emits a spherical wave with set amplitude and known phase. The resultant sound field at each point in the 3D space is the complex sum of the waves that propagate from each transducer. While this scheme is fairly simple to program, it can take a bit of processing power to execute, but the result should be a good representation of the 3D sound field.

The data will come in the form of images. Schlieren imaging is essentially a 2D projection of a 3D index of refraction perturbation. An ultrasound field represents a complex perturbation of the air pressure (hence index of refraction), and it occupies a 3D volume of space. This can be a standing wave (as in a cavity) or a traveling wave (as in free space). In either configuration and as indicated earlier, our pulsed LED scheme essentially "freezes" the sound field in place, which guarantees the projections will be authentic projections of the same sound field. As the sound field is rotated to set angles, data will be collected from our DSLR camera in the form of 2D images and cleaned with ImageJ (imagej.net). We will then use the inverse Radon transform [2] to reconstruct the 3D image. Largely known in medical imaging, the Radon transform is a well-known method of projecting the 2D output from the propagation of x-rays through a 3D material. The inverse Radon transform is the tomographic reconstruction of that 3D image from the collection of 2D images. With an appropriate number of recorded 2D images at specified angles, a reliable 3D density plot can be reconstructed. This will allow us to properly compare our resultant sound fields with our predicted sound fields.

Dissemination of Information

Project members have strong interest in presenting their work at both academic and professional conferences, as well as student symposiums. SDSU hosts an annual research symposium where students present their academic research or creative activities. The SDSU SPS research group will certainly have a presence at the symposium, many members have expressed interest in presenting a poster or giving a talk.

Previous support from the SPS Chapter Research award has resulted in a publication in the *Journal of Undergraduate Research in Physics and Astronomy* [3]. Several oral presentations have been given on the work as well. In March 2025, a project member was awarded as the top presenter in their undergraduate oral session at the APS Global Physics Summit. Another talk was given in October 2025 at the APS Division of Laser Science Student Symposium. The symposium was held in conjunction with the Optica Frontiers in Optics + Laser Science meeting.

Plan for Carrying Out Proposed Project

The project personnel will mostly be made of undergraduate members of the San Diego State University SPS chapter. Project members will be involved in several aspects of the project: Numerical modeling, experimental design and measurements, and data analysis. Project members will also gain experience in giving oral/poster presentations as well as manuscript writing.

The proposed project is interdisciplinary, pulling topics from fields such as optics, electrical engineering, fluid mechanics, etc. Most project members have some experience in the fields mentioned above. Other members are relatively new to the study and are learning the proposed methods and subject as the study progresses.

Along with student experts, there are several SDSU faculty members (from the departments of Chemistry, Mechanical Engineering, and Computer Engineering) who have provided both equipment and technical advice. Researchers from external institutions have also offered guidance on the project. Project members have been in contact with authors of a paper regarding the construction of an FPGA based phased array of transducers [4], for technical guidance.

Most research activities will take place in Dr. Matt Anderson's experimental optics lab. Dr. Anderson also serves as the SDSU SPS advisor, he is available for project guidance. The SDSU department of Physics is in great support of the project's initiative. A space has been provided for the group to host weekly meetings. The department has also played a role in financially supporting undergraduate students for their conference travel. More recently to the 2025 American Physical Society Global Physics Summit and Sigma Pi Sigma Con 2025.

Project Timeline

January 2026: Design phased transducer array FPGA circuit and start developing numerical models for the tomographic view.
February 2026: Assemble phased array of transducers, program FPGA, and continue modeling sound field.
March 2026: Test FPGA circuit and prepare to present at SDSU Student Symposium.
April 2026: Take measurements of the sound field from different angles.
May 2026: Write SPS interim report.
September 2026 - November 2026: 3D image reconstruction of the sound field and prepare to present at 2026 Optica FIO + LS.
December 2026: Write final SPS report and prepare manuscripts.

Budget Justification

Electrical equipment makes up a major expense category for the project. Items such as wire and solder are used in high demand. Many of our current essentials such as a soldering iron, multimeter, oscilloscope, and wiring tools are borrowed from various professors and labs on campus, mainly Dr. Matt Anderson. Our group has access to his experimental optics lab, where we perform all of our measurements. For a tomographic approach to Schlieren imaging, having a rotating optical breadboard is crucial in order to rotate the ultrasound field.

The second largest portion of our budget contains FPGAs. We have conducted preliminary testing with an Arduino Mega, which can drive six ultrasonic transducers maximum, as well as a group member's personal Tang Nano 20K FPGA. Having several preliminary FPGAs will allow us to push the boundaries and experiment with. Obtaining results with low-cost hardware increases the accessibility of our final product for physics educators to use as a demonstration. For optimal performance, as well as industry-standard education of our project members, a Nexys Artix 7 FPGA development board with specific pulse width modulation outputs for our transducers and expansion connectors is needed to drive an ultrasonic array.

Updates to PPE and broken equipment, such as a faulty multimeter, is essential to our research activities. For example, we have fewer functioning ear protection muffs than people in our lab, and hearing safety is critical when working with ultrasonic waves.

Bibliography

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[2] J. Radon, "Über die Bestimmung von Funktionen durch ihre Integralwerte längs gewisser Mannigfaltigkeiten," *Classic Papers in Modern Diagnostic Radiology* **5** (21), 124 (2005).

[3] F. Poutoa, A. Rodriguez, L. Welstand, M. Becker, S. Duckworth, R. Palmares, C. Patino, and M. E. Anderson, "Schlieren imaging of ultrasound wave interference," *J. Undergrad. Res. Phys. Astron.* **34**, 1 (2025).

[4] S. Zehnter and C. Ament, "A modular FPGA-based phased array system for ultrasonic levitation with MATLAB," in *Proc. 2019 IEEE Int. Ultrasonics Symp. (IUS)*, pp. 201–204 (2019).