# How a Basement Inventor Builds Volumetric Displays

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## ABSTRACT

This interactive session introduces participants to a systematic approach to building solutions for difficult problems. By looking at the challenges the author faced when building a volumetric display, the session participants are invited to engage in a discussion of problem-solving techniques that could potentially be applied to this domain area. Participants will come out of this session with an alternative set of tools and an appreciation for what is possible to accomplish by those with a limited budget and resources (aka the basement inventor).

## CCS CONCEPTS

• **Hardware** → Displays and imagers; • **Social and professional topics** → Informal education.

## KEYWORDS

Volumetric displays, prototyping

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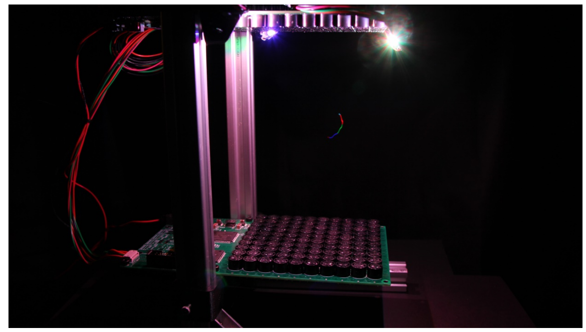

**Figure 1: The author's volumetric display using an acoustically trapped particle moving at high speed to draw an image in mid-air, illuminated by RGB LEDs**

## 1 INTRODUCTION

Hobbyists, usually with limited resources and budget, require innovative ways of thinking and building to achieve their goals. The hobbyist is usually trying to explore new technologies to build something "cool" and innovative – impressing themselves is usually the target as few others will appreciate and understand the challenges one faces when building a project and solving problems along the way. The development of volumetric displays is just such a challenge that many would shy away from even attempting. However, by following a systematic approach to breaking down a problem and addressing each challenge, even the most seemingly complex of devices can be built by the hobbyist in their basement or garage.

## 2 VOLUMETRIC DISPLAYS

In contrast to a standard (flat) two-dimensional display, a volumetric display is one that displays images in three-dimensions without the need for assistive devices (e.g. 3D glasses). There are many ways to achieve this but many commercially available systems use some sort of swept volume approach, whereby an light-emitting set of pixels or a reflective screen onto which is projected an image is moved through a volume of space rapidly enough that the eye perceives a single continuous 3D image through the Persistence of Vision effect.

This workshop will explore the development of one such type of display that the author has designed and built, which on the surface may seem to be extremely complicated. The workshop will present to the audience a variety of challenges the author faced during development and guide the participants in a discussion of how these challenges might be addressed. The goal is to have the audience leave the workshop with some of the tools required to decompose challenging problems into a series of questions to be answered and some tips on the development of experiments that can help answer those questions, all on a hobbyist budget.

## 3 VDATP – VOLUMETRIC DISPLAY USING ACOUSTICALLY TRAPPED PARTICLES

VDATP is a project based on a 2019 Nature journal article [Hirayama et al., 2019]. In it, the researchers described an apparatus that uses phased arrays of ultrasonic transducers to levitate and translate a small 1-3mm foam ball onto which RGB light is projected. By moving the ball at high speeds (i.e. >1m/s), it is possible to "draw" images in mid-air at high enough frame rates (>10FPS) that the eye perceives them as (relatively) solid. The author was able to replicate this result in his basement in the span of 3 months on a budget of approximately $500.

What follows are a number of challenges that had to be addressed by the author in the construction of VDATP – each challenge provides an opportunity for conversation with the audience to brain-storm on approach and resolution of these problems.

### 3.1 The Physics

One of the most important issues to be resolved before building this was to determine the physics of acoustic levitation. The solution


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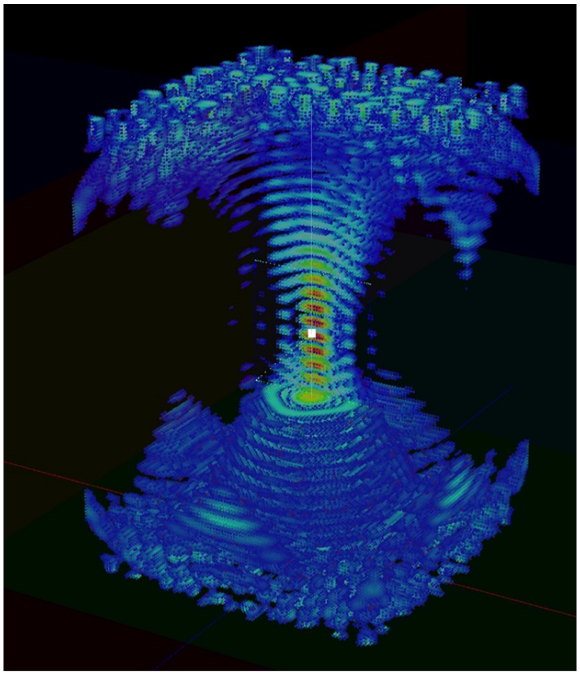

**Figure 2: Simulation of interfering acoustic pressure waves generated by two opposed phased 10x10 arrays of ultrasonic transducers**

involves two arrays of ultrasonic transducers spaced approximately 15cm apart. Each transducer emits 40kHz ultrasonic sound – by changing the relative phases of each transducer, it becomes possible to create an area of highly focused acoustic pressure waves by constructive and destructive interference where a small particle can be levitated. The original Nature paper lists a formula that allows the calculation of the phase delay $\phi_T$ for each transducer given a focus point $p$:

$$\phi_T = \left(-\frac{N}{2\pi} \cdot k \cdot d\left(p,\ p_t\right)\right)\ mod\ N$$

Where $N$ represents the number of discrete phases that the system can generate, $k$ the wave number ($k=2\pi/\lambda$), $p_t$ represents the position of the transducer and the function $d$ calculates the Euclidean distance between two points. While this formula looks relatively simple, the author chose to build a simulation to visualize the pressure waves and create control algorithms – this allowed for quick experimentation of various parameters and configurations and also validated the physics.

## 3.2 The Hardware

The development of the hardware posed a number of unique challenges, including basic architectural design, low-cost component sourcing, schematic design, PCB design and manufacturing. Perhaps the most important part of this process was the evaluation of various failure modes and the development of approaches to mitigate those potential failure modes. This is one area where experience and skill come into play – the manufacture of hardware is the sole expense in such a project and given that the parts cost alone approached $500, minimizing the number of revisions is important to the basement hacker. Some best practices from the author's experience will be presented in this section, with an invitation to the audience to share their own best practices.

## 3.3 The Firmware

The author chose to implement this design using a set of FPGAs and the firmware was developed using an iterative approach. As a first step, the FPGAs were programmed as a set of signal generators, one per transducer, whose phase could be changed upon command from a PC. This allowed the control algorithm to be developed in relative comfort on a larger, more capable machine. As a next step, the step of calculating the phase for each transducer was moved to the FPGA. This involved the development of FPGA simulations and a variety of interesting in-system testing techniques – these will be presented as well. In the last step, a motion controller was developed for the FPGA that allowed it to independently move the ball and change the LED colors.

# 4 SUMMARY

By breaking down a seemingly intractable problem into a number of discrete challenges, the author shows that a systematic approach can be used to successfully build solutions to these problems, which in this case is the development of a rather unique volumetric display. The development of such solutions can take often multiple paths and those are highlighted by the author during the presentation. At the end of this presentation, it is hoped that audience members will have some of the tools needed to address their challenging builds and will be inspired to build something they didn't think was possible.

# REFERENCES

Ryuji Hirayama, Diego Martinez Plasencia, Nobuyuki Masuda, and Sriram Subramanian. (2019) *A volumetric display for visual, tactile and audio presentation using acoustic trapping*. Nature, 575 (7782). pp. 320-323. ISSN 0028-0836