The digital holography demonstration: a table-top setup for STEM-based outreach events

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The Digital Holography Demonstration:  
A table-top setup for STEM-based outreach events

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ABSTRACT

The SPIE Student Chapter at the Air Force Institute of Technology (AFIT) is spearheading a new outreach project to encourage science, technology, engineering, and mathematics (STEM) in grades K-12. This new outreach project is referred to as the Digital Holography Demonstration (DHD). Using a table-top setup, the DHD estimates the both the amplitude and phase of the complex-optical field, and in so doing, illustrates several fundamental optics and photonics principles including diffraction, refraction, and the interference of light. These fundamental optics and photonics principles have direct ties to current technologies being developed in the medical, astronomy, and defense communities (to name a few). This paper celebrates the resourcefulness of the DHD for STEM-based outreach events and provides a parts list, cost breakdown, and brochures, so that future efforts can benefit from its design.

Keywords: digital holography, spatial heterodyne, STEM, outreach, SPIE student chapter, optics and photonics, SPIE Optics Outreach Games, physics education

1. INTRODUCTION

The DoD’s investment in optics and photonics has led to significant advances in remote sensing, astronomy, industrial processing, and medical technology. To celebrate this rich heritage and promote public awareness in science, technology, engineering, and mathematics (STEM), the SPIE Student Chapter at the Air Force Institute of Technology (AFIT) participates in a wide range of outreach efforts. Most of these outreach efforts involve interactive demonstrations of electromagnetics, thermodynamics, and optics. With this in mind, the laser propagation demonstration (LPD) was the cornerstone for these outreach efforts¹, and the LPD is the result of a 2010 SPIE LaserFest Grant and a 2012 SPIE Outreach Grant.

After more than 5 years of continual use (in its current form), the LPD needed new parts; thus, we decided to change its design. As shown in Fig. 1, the resultant Digital Holography Demonstration, or DHD for short, leverages existing parts from the LPD to create a new table-top setup—one that is appropriate for a wide-range of audiences. This setup is the result of a 2018 SPIE Outreach Grant that we proudly debuted at the 2018 SPIE Optics Outreach Games in San Diego, CA.

In what follows, Section 2 of this paper provides an overview of the DHD. Here, the reader gets to see background material in the form of a brochure that will accompany the DHD in future outreach events. Section 3 then provides an overview of DHD’s design and refers to a parts/price list located in the Appendix of this paper. Using this parts/price list, the interested reader can build their very own DHD! Section 4 provides a conclusion for this paper with a roadmap for future upgrades that are currently in the mix.
2. OVERVIEW OF THE DHD

As shown in Figs. 2 and 3, illustrative brochures help the audience members to follow along with the overall demonstration. As a result, it is also our belief that the DHD is appropriate for a wide-range of audiences from our participation in many and varied outreach efforts with the LPD. For instance, sometimes you have 30 seconds to engage a passerby (given a booth-based expo) and sometimes you have the whole day to setup numerous lessons (given a classroom endeavor). The DHD is appropriate for all audiences, and it gives the AFIT SPIE Student Chapter the flexibility it needs to participate in a wide range of STEM-based outreach efforts.

To increase optics and photonics awareness to our target audience, the DHD will become the cornerstone of our chapter’s outreach efforts. The goal is to use the DHD to give audience members a basic understanding of fundamental optics and photonics principles. For example, people who have less than perfect vision contain phase aberrations in their eye. When a person undergoes laser-eye surgery, the aberrations are first measured and then corrected by reshaping the cornea to improve vision. By connecting the principles illustrated by the DHD to more commonly known applications, optics and photonics becomes more relatable to audience members.

The majority the AFIT SPIE Student Chapter’s outreach efforts include audience members which consist of young students (K-12) in the local community. Additionally, many of the students have not been exposed or are under exposed to optics and photonics. The DHD will enable our chapter to increase our demonstration capabilities to connect with these students. Since we always strive to have a strong impact with students, we also aim to motivate students to become the next generation of scientists and engineers and use optics and photonics to make significant advances in STEM.

Moving forward the DHD will be showcased at our chapter’s many and varied outreach efforts with special attention given to SPIE (which made it all possible). Furthermore, the illustrative brochures (cf. Figs. 2 and 3) denote the special consideration received from our 2018 SPIE Outreach Grant. We planned to have the DHD completed by the 2018 SPIE Optics + Photonics Conference, so that we could showcase it in the 2018 SPIE Optics Outreach Games and present in Optics Education and Outreach V—accomplishments that we are now proud to showcase in this paper.

Figure 1. The DHD being debuted at the 2018 SPIE Optics Outreach Games in San Diego, CA.
Light travels as a wave with an amplitude and a wavelength. Most light sources, like the sun, are composed of many different wavelengths. Laser light is special because it is composed of a single wavelength.

When the laser light is split into a reference and signal beam, the two beams interfere to produce a hologram. This interference is then recorded by a camera as a digital hologram.
Digital Holography enables us to image through distributed-volume aberrations, such as those caused by atmospheric turbulence. Using digital holography and novel image processing algorithms, such as those distributed-volume aberrations, we can resolve distant objects at range for military applications. For example, we can use digital holography and novel image processing algorithms to image through skin without the need for invasive procedures.

**Digital Holography**

Aberration

Corrected

Original

Hologram

2D FFT

Digital Holography Applications
3. OVERVIEW OF THE DHD’S DESIGN

The DHD uses an eye-safe, battery-powered visible laser diode with a 532 nm wavelength to create a reference beam and signal beam. As shown in Fig. 4, the signal beam travels through an object mask (and potentially a phase aberration) before being interfered with the tilted reference beam onto a camera. We then process the resultant digital hologram on a laptop to gain access to an estimate of the complex-optical field\(^2\) (i.e., both the amplitude and phase), as shown in Fig. 5.

Provided the complex-optical field, we aim to display the following three things on the laptop screen (and a larger screen if available): 1) a degraded image of the object mask (implemented), 2) the phase aberration that degrades the image of the object mask (implemented), and 3) a corrected image of the object mask via digital-signal processing referred to as aberration correction (future work). In so doing, the DHD illustrates three main teaching objectives. The first objective is to demonstrate the wave and particle nature of light. The interference between the signal and reference beams is only possible due to the wave nature of light and the resultant digital hologram is only possible due to the particle nature of light. A second objective is to make it clear that we can only measure the power per unit area or irradiance of the complex-optical field with the camera. This outcome is the result of the optical oscillations being too frequent to measure the complex-optical field directly. In response, we can gain access to an estimate of the complex-optical field through the interference light and digital-signal processing. The third objective is that aberration correction\(^3\) is possible because of digital-signal processing and has led to significant advances in remote sensing, astronomy, industrial processing, and medical technology. From these three main teaching objectives, it is our belief that audience members will walk away from the overall demonstration with a basic understanding of fundamental optics and photonics principles.

The Appendix to this paper contains the parts list needed to build the DHD. For us, these parts complemented the previously procured parts for the LPD\(^1\), which saved us approximately $1500 in overall costs. Based on this parts list, we asked for and received $3900 from our 2018 SPIE Outreach Grant. These funds, in addition to our yearly chapter budget, enabled the AFT SPIE Student Chapter to outright own the parts needed for the DHD. In turn, we will have dedicated access to the DHD for our future outreach events. The reader should note that we will also use our yearly chapter budget to support extraneous costs, such as food and beverage costs and brochure-printing costs.

![Description of the DHD](https://nanolithography.spiedigitallibrary.org/conference-proceedings-of-spie)

**Figure 4.** Description of the DHD. A parts/price is given in the Appendix.
Figure 5. A detailed look at the processed a.) phase and b.) amplitude in the image plane given a specified region of interest (blue square) in the hologram plane. The reader should note that the appropriate term is windowed in the Fourier plane (blue circle) to obtain these results.
### 4. CONCLUSION

This paper reviews the recent completion of the DHD—AFIT’s new outreach effort in optics and photonics. It is our hope that the interested reader can improve our design and share it with the STEM-based outreach community. The SPIE Student Chapter at AFIT plans to continually upgrade the DHD as well. In the near future, we plan to implement the ability to perform aberration correction using additional digital-signal processing.

The views expressed in this paper are those of the authors and do not reflect the official policy or position of the U.S. Air Force, Department of Defense, or the U.S. government.

### APPENDIX

Table 1 below gives a parts/price list for the DHD design shown in Fig. 4.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Item Product URL</th>
<th>Qty</th>
<th>Price</th>
</tr>
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Table 1. Parts/price list for the DHD.
REFERENCES


