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Laser Illuminated Projectors and their Benefits for Immersive Environments

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Abstract

Laser-based illumination sources for projection systems are becoming a powerful alternative to conventional lamp-based light sources. The laser-based lights have a multitude of advantages over conventional lights, including brightness, longevity, scalability and others. The work described here looks at these advantages from a point of view of large-screen projection systems as used for immersive Virtual Reality systems. For these applications laser-based light sources are very useful, especially when using Infitec-base stereo glasses.

Introduction

The main premise of Virtual Reality (VR) is to create and provide a Virtual Environment (VE) that the user can be fully immersed in, that provides a new, virtual world they can explore, interact with, enjoy and work in. Initially, this was realized through head-mounted displays (HMDs), where two small displays (one for each eye) were attached to the user's head to permanently provide a 3D stereo image that adapts depending on where he or she is looking and what changes happen in the virtual world.

HMDs face significant challenges, though. Because they are worn on the head, they need to small and light, severely limiting the number and quality of pixels that can be displayed. Recent developments like the Oculus Rift or the HTC Vive and many others benefit from developments in small, high-resolution screens for cell phone use to provide a much better quality than was possible not too long ago, especially compared the beginning of VR, but they are still nowhere near the capabilities of the human eye.

HMDs also have other limitations, as they completely disconnect the user from the physical world, including the user's own body and other people around them. The loss of their own body can be very confusing for users, and limit acceptance and usability of the systems. HMDs also have limited use for scenarios that require more than person to communicate directly with each other, for example to review plans of any kind and being able to point out areas of interest or contention to each other.

To overcome these limitations alternative design to provide an immersive display environment based on large-screen projection systems (LSPS) have been designed. The most famous and most immersive one is the CAVE [1], which surrounds the user with projection screens, and allows presenting a fully immersive environment without limiting the user's ability to see their own body or communicate with other people in the same environment.

But LSPS come with their own share of limitations. One challenge is how to present a stereoscopic images to the viewer. For HMDs this is straightforward, as each eye has a separate screen. In projection systems both eyes see the same screen, and need additional hardware to separate out the different images for each eye.

In recent years a new technology for LSPS projectors has become feasible: laser-based illumination sources. These have several advantages for general projection-based system like movie theaters and conference rooms and are becoming commonplace.

The goal of this work is to look at laser illuminated projectors to see if and which advantages they can provide for Immersive Environments. It is structured as follows: section Background provides a background on LSPS, stereo displays and the history of laser-based projections. Section Laser Projector Principles describes the different methods that are used to build laser-based projectors today. The advantages of laser projectors are described in sec. Laser Advantages, the disadvantages in sec. Laser Disadvantages. Section Conclusion and Future Work summarizes results and looks at possible future developments.

Background

Large screen projection systems and laser-based display system have a long history and a variety of alternatives for problems like stereoscopic display.

Large-Screen Projection Systems

As the name implies, large-screen projection systems consist of one or more large screens (typical sizes are in the 10-12 ft range), driven by large projectors, that display stereo images which are calculated for the user's perspective (based on their head-tracked eye positions). Due to the size of the screens and the light lost due to the stereo capabilities (see section Stereo Display for LSPS), brightness has always been a challenge for LSPSs, requiring large, expensive, high brightness projectors. They can also be limited by the resolution of the projector, depending on how close users get to the screen in normal operation. Both of these challenges result in costly installations. But the ability to be immersed with minimal inconvenience has resulted in many high-end installations over the years.

The most widely known and most immersive system is the CAVE [1]. In the best case, it consists of 6 projection screens that fully surround the user and enable them to completely disconnect from the real world, without disconnecting from their body. Smaller installations typically have 3 or 4 sides (see Figure 1), due to the very high cost of building larger installations (6-sided CAVEs require rear projection on all sides, resulting in installations that cover three floors of a typical office building, Figure 2 shows the installation at Iowa State University).

Typical large scale projectors consist of a high-powered light source (like one or more Xenon or mercury (UHP) arc lamps) that provide the raw light that is then modulated by spatial and color filters. Spatial filters can be LCD or LCOS panels, or DMD de-

Figure 1. *User in 4-sided CAVE at UALR*

Figure 2. *6-sided CAVE installation at Iowa State University*

vices (known as DLP projectors). The color filters can be separate color filters for red, green and blue, which then drive 3 separate spatial modulators, or integrated (single-panel LCD) filters, or time-multiplexed (color wheel for single-chip DLP) for lower cost.

Stereo Display for LSPS

Projection systems, similar to 3D monitors, need to find a way to present two images, for the left and right eye of the user, on a single screen, and then separate them again before they reach the user's eyes. There are a variety of options on how to do that, all with different pros and cons.

Polarization

Polarization filters are a simple, widely used option. Two images (usually from two separate projectors) are sent through different polarization filters, which are mirrored in glasses that the user wears to separate the two images. Linear or circular polarization are possible.

Polarization is attractive because the glasses are cheap and can be used for large groups. This is not as much of a benefit for most immersive systems, as the number of users tends to be small. The disadvantage of polarization is that the separation quality between eyes is generally not very good [2]. This is known as cross-talk, and results in double images where one eye can see a shadow of the other eyes image. This leads to reduced immersion and even to user fatigue and sickness.

Polarization can be problematic, depending on the projector technology. Some projectors generate polarized light (this includes some laser-based projectors), which when run through a polarization filter can result in black images. It is hard to predict which projector will have issues here, making projector selection complicated. Polarization also requires compatible screen materials that maintain the polarization. Especially for rear-projection screens, which are typically used for immersive installations, that can be very challenging.

Active Stereo

Active stereo uses time-based multiplexing, where the two images are displayed sequentially, one after the other, at a very high speed (typically 96 to 120 Hz). The user wears glasses that black out one eye when the other eye's image is being displayed. The projectors need to be able to display images at the required high update rate, which can be a challenge for slower technologies like LCD or LCOS.

Active stereo glasses are more expensive, but provide better stereo separation. Laser light sources are independent of the active stereo process, so they can be used with active stereo glasses very well.

Infitec / Dolby3D

Infitec [3] is a technology that uses color filters to separate the left and right eye images. Each filter has three very narrow pass-bands for red, green and blue, so it can provide a full-color image. There are two versions with slightly different pass-bands for left and right eye separation (see Figure 3).

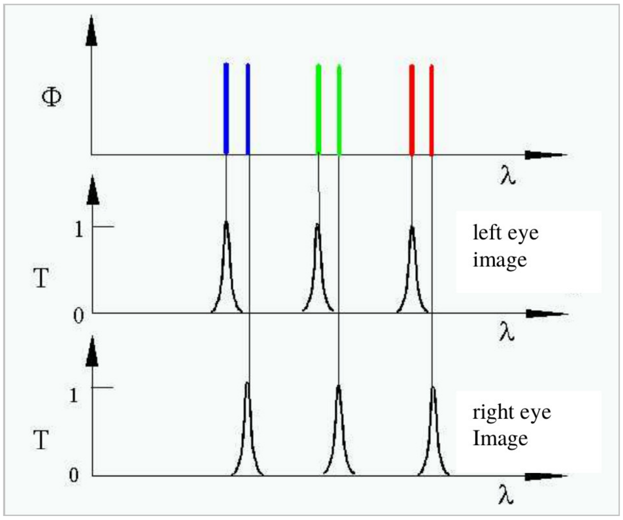

Figure 3. *Infitec Filters*[1]

Infitec provides very good eye separation with minimal cross-talk. Also, because it only depends on color, it can be used with any screen material. The glasses are rather expensive, but that is not a significant problem for most immersive installations.

One challenge with Infitec is that the two filters necessarily use slightly different colors. Depending on the displayed scene, this color difference can be very noticeable, if it is not corrected in the VE software or the projector itself. High-end projectors will do this, lower-end or standard projectors with attached Infitec filters will not, and require correction in the VE software.

The major limitation of using Infitec with standard bulb-based projectors is the fact that the pass-bands of the filters are very narrow. As a consequence, only the part of the projector brightness that fits into that narrow band will actually be used, everything else will be absorbed by the filter. This problem is even exacerbated by the fact that the spectrum of a typical UHP or Xenon lamp as used in normal projectors is not flat at all, it has significant spikes (see Figure 5, top). When this spectrum is filtered through the Infitec filters (see Figure 5, middle and bottom), only a very small percentage of the light comes through.

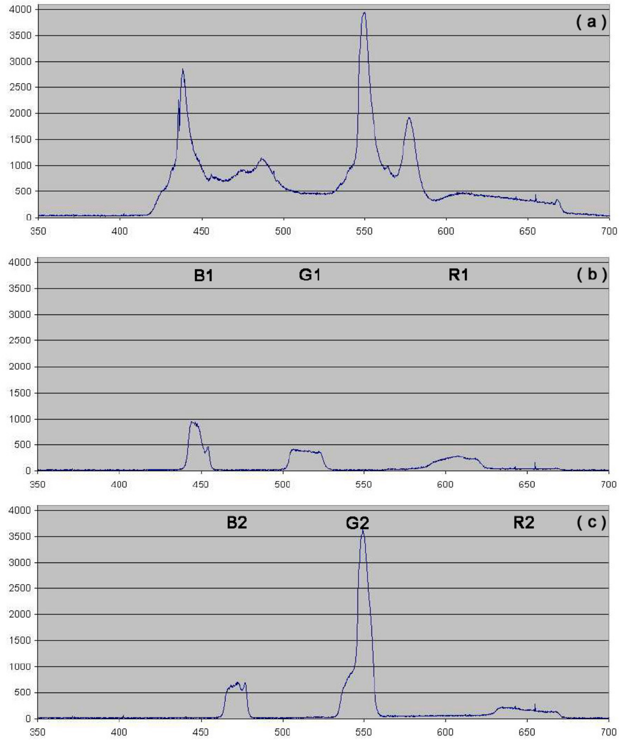

Figure 4. (a) UHP lamp spectrum, (b)/(c): spectrum after the left/right Infitec filters [1]

As a consequence, Infitec-based systems require projectors that produce a large amount of light, only a small portion of which will actually be used. As brighter projectors are more expensive, produce more heat and require more maintenance, many Infitec-based installation tend to be very dim, limiting immersion quality.

History of Laser Displays

Using lasers as a light source is not a new idea. In fact, a patent was granted in 1966 [4] for a laser-based TV display, and a functioning prototype developed by Schneider was shown at a trade show in 1995. It was never turned into a product for the TV market, due to prohibitive cost and financial troubles of the inventing company.

However, the technology was extended into a projector-based system developed by Schneider Laser Technologies in collaboration with Zeiss. Zeiss called it ZULIP (Zeiss Universal Laser Image Projector). It was first demonstrated in the early 2000s (for example at the Cybernarium Days 2002 in Darmstadt, Germany [5]) and installed as part of planetarium installations in Germany and Austria [6, 7]. It already featured the laser/modulator separation that is one of the advantages of a laser projector (see Scalability). Given the size of the system, this was a fairly obvious requirement (see **??**).

Figure 5. Schneider/Zeiss Laser Projector main unit and projection head (2001) [3]

Zulip used 3 separate lasers for red, green and blue (see section RGB Lasers) and a scanning mirror system, similar to the ones used for laser printers. The big advantage of the scanning system was the practically infinite depth of field, there was no focus plane, and the projector was able to project a sharp image on multiple arbitrary curved surfaces at different distances from the projector. This made it especially attractive for planetarium installations, as it could project a large, focused image onto the planetarium dome from a single projector.

However, due to the high cost of the system, to a large extend caused by the large, expensive RGB lasers, it never become a commercial success and disappeared. The base technology is still being developed by LDT, but commercial projectors are not in the market any more.

In the following years laser-based TVs made a few appearances at trade shows, made possible by developments in laser diodes, which reduced the cost significantly. But the prices were still high, availability was limited and long-term reliability was a challenge. Even though some commercial laser TV products were launched, they did not succeed in the market.

This changed in the mid 2010s. In 2013/2014 the first laser illumination based projectors made an appearance, and they are poised to take over a significant part of the projection market.

Laser Projector Principles

The name ’laser projector’ is really not an accurate description for today’s projectors. They use lasers as an illumination source that is used to drive a spatial modulator (LCD, LCOS or DMD/DLP) that defines the actual image. In that sense the laser only replaces the Xenon or UHP light bulbs that are used to drive standard projectors. The challenge, and the reason it took until very recently before laser projectors became viable, is to create the three colors red, green and blue using lasers in a cost-effective, long-term maintainable form. There is not just one solution to this problem, different manufacturers use different approaches, even for different product lines.

RGB Lasers

The most obvious solution is to use separate red, green and blue lasers. This is the easiest to understand and cleanest solution, but due to the differing cost of different kinds of LEDs (red and green can be expensive) it tends to be more expensive overall. That expense can be alleviated through sharing of light sources (see sec. Scalability), but projectors using RGB lasers tend to be more expensive.

Laser + Phosphor

An alternative that is starting to be popular is the use of a single color laser (typically blue) that is used in conjunction with a phosphor that, when excited by the laser, emits a different color of light (typically yellow). The secondary color emitted by the phosphor is not a single wavelength like the laser, it is a mix of wavelengths that can be separated into usable colors like red and green through the use of color filters. The rest of the system works the same as in the RGB case.

The advantage of this system is that only one color laser is needed, but at the cost of a more complex system that often contains mechanical parts (the phosphor is often on a spinning disk to increase longevity), which can increase failure rates.

Laser + LED Hybrid

The final approach is to use a hybrid that combines laser diodes with standard light emitting diodes (LEDs). As LEDs are simple to build, they are cheaper, but at the cost of lower light emission, requiring more LEDs to get the same amount of light. Depending on the relative cost of laser vs. regular LEDs, this can still be beneficial.

However, the main limitation of using LEDs is the achievable brightness, which is significantly lower than that achievable using lasers or standard lamp-based techniques. Pure LED projectors and even laser hybrids are going to have a hard time reaching the brightness required for an LSPS on the large size screens needed for those.

Laser Advantages

The reason projectors companies are adopting laser systems is not just because lasers are cool (although it is a factor), but because of significant advantages of laser illumination over other light sources.

Longevity

One of the main problems with Xenon or UHP light bulbs is their lifetime. They typically have lifetimes between 2000 and in the best case 3000 hours, but manufacturers recommend changing them at around half that time due to the brightness lost with aging. That may sound long, but for a system that is in use 8-10 hours a day, it means exchanging bulbs every one or two years. This is a problem for immersive installations, which often use multiple projectors together, as these kinds of bulbs are expensive.

In addition to that, they also lose brightness over their lifetime relatively quickly, often in an exponential fashion. As a consequence it is not always feasible to exchange only the old or broken bulbs, typically all bulbs in an installation need to exchanged at the same time to maintain constant brightness and brightness development across the whole system.

Laser diodes generally age in a more linear fashion, reducing the effect of lifetime changes. Laser light sources, due their much lower heat generation and more robust mechanical construction, typically are quoted to have an expected lifetime of 30,000 hours, phosphor laser systems typically are expected to last 20,000 hours. They are also less sensitive to their environment conditions and need less service overall.

This can significantly reduce the operational cost of running an installation.

Effectiveness

Looking back at the spectrum of a UHP lamp (see Figure 5) it becomes fairly clear that no matter which primary colors a projector uses, a significant part of the generated energy cannot be used and needs to be absorbed. This is one of the reasons projectors need significant cooling, requiring expensive, controlled environments and regular maintenance.

Laser light sources, in contrast, only generate very narrow wavelength signals, and can be used directly as the primary colors without any color filtering necessary.This enables laser projectors to generate the same amount of usable light with significantly lower input power, further reducing operational cost.

Color Range

Because the lasers create light of a single wavelength, they can cover points on the very outside of the color spectrum, allowing them to cover a much larger area of the color spectrum (see Figure 6).

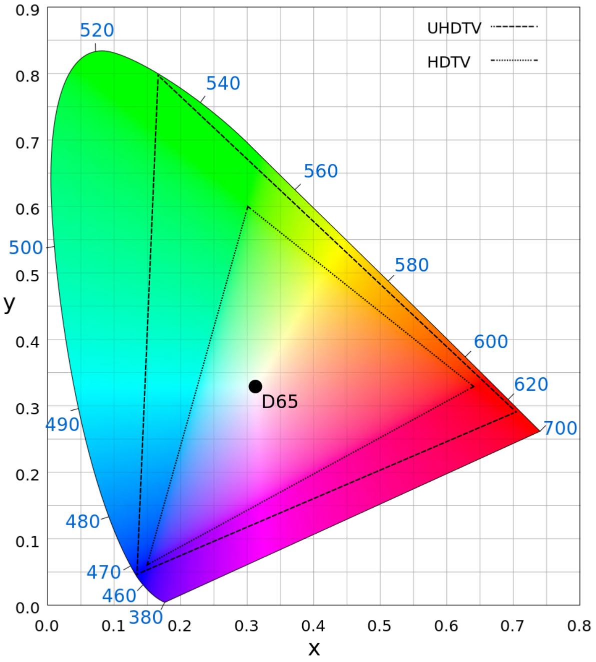

Figure 6. Color space comparison. UHDTV is the Rec2020 spec, which laser projectors cover almost completely, HDTV is the Rec709 spec for HDTV TVs [5]

This leads to brighter, more saturated colors and the ability to display more lifelike scenarios. This is important in many situations in which real-life objects need to be displayed, e.g. for design reviews, and will allow a laser-based system to provide a higher level of immersion than other projector technologies.

Robustness

One of the main failure points of a standard lamp projector is the lamp. Most projectors only have one or a small number (2, rarely more) lamps combined to generate the needed light. Diode-based projectors are inherently more robust, because they use a large number of diodes (often in modules of 20 or more). If a single diode fails, the light output is only reduced by a few percent, instead of totally or by half.

Also, because they generate a lot less heat and therefore need less cooling, laser projectors can be used in much harsher environments than lamp-based projectors.

Scalability

Laser-based projectors are easier to scale, because the

Laser-based projectors are inherently easier to scale, as they use a multitude of diodes already. Thus adding additional modules requires some scaling, but no fundamentally new developments, the same style diffusion and condenser components can be used.

An additional opportunity arises in installation with multiple projectors, like typical LSPS installations. Because the technology to transmit laser light through glass fibers is well developed and widely supported by optical networking components, it is fairly easy to transmit the laser light over larger distances with little effort beyond laying fiber.

This enables building systems that decouple the light source from the modulator component, and to combine the light sources for multiple projectors, simplifying maintenance and cooling management. In the end, all the light sources for an installation can be combined in one or more standard 19” computer racks (see Figure 7).

Figure 7. Example racked light sources [6]

Infitec / Dolby3D Support

The final advantage of laser over conventional light sources is their suitability for supporting Infitec-style stereo displays. As described in sec. Infitec / Dolby3D, one of the problems with Infitec is the extremely small amount of light that actually makes it into the user’s eyes, compared to what the lamps generate.

Laser-based illumination sources can completely avoid this problem. By using 6 different primary laser colors instead of the usual 3, it is possible to directly generate the required wavelengths for correct Infitec display. As a result the projectors do not need to have any filters, avoiding the corresponding light loss. The only filters needed are the ones in the users’ glasses, consequently the amount of light lost due to the 3D stereo display is minimized and significantly lower than with regular projectors.

Using laser light sources enables very bright, very low cross-talk 3D stereo displays, making them extremely suited for Virtual Environment displays.

Laser Disadvantages

Of course, laser light sources don’t only have advantages, they also provide some challenges. The main (potential) problem for using laser illumination is the speckle effect.

Speckle

Speckle is an effect that makes a surface that is illuminated by a laser light to look non-uniform or speckled (see Figure 8 for an example). The effect is very easy to observe using any conventional laser pointer shining on a rough surface.

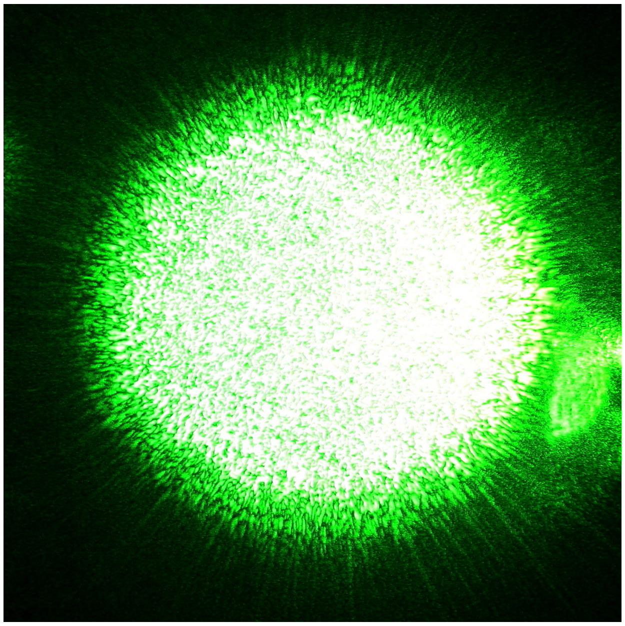

Figure 8. Laser speckle [7]

The speckle pattern is caused by interference between the laser wave fronts. Laser light by its nature is coherent, all light waves have the same frequency and the same phase. When such a light bundle it reflected by a rough surface, some of the wave fronts interfere destructively, i.e. they cancel each other out, resulting in a dark spot on the surface.

To avoid this problem, the coherence needs to be reduced. For Laser-phosphor systems (see sec. Laser + Phosphor) this is naturally the case, the excited phosphor does not create coherent light. For the laser components this is a little more difficult.

The fact that laser light sources are composed of many individual diodes enables the manufacturers to slightly vary the frequency of the different diodes, removing the major cause of speckle. It can also be helpful to distribute the orientation of the diodes as well as depolarizing the light [8, 9]. More complex methods exist, e.g. using dynamically deforming mirrors [10].

In practice the problem of speckle exists, but is well under control by the manufacturers.

Conclusion and Future Work

Laser-based illumination sources for projected Virtual Reality displays have a great potential. They provide high-quality, vibrantly colored and bright images, which is important to counteract the brightness that is lost through the 3D glasses needed for immersive Virtual Reality. Due to the nature of the laser light sources, it is possible to directly generate the narrow-band RGB combination needed for Infitec-style 3D glasses, reducing the need for filters and minimizing the loss of light even more.

Overall, a 6p RGB laser light system promises to provide the best image vibrancy and color quality of any of the reviewed methods to drive large-screen projection systems for Virtual Environments.

The results described in this work are all based on theoretical methods and conclusions. We are working on acquiring an actual 6p laser light system to enable us to do concrete measurements and put the theory to the test.

Acknowledgments

We would like to thank Power Technology, Inc. for their support in preparing this publication.

Image Sources

[1] Infitec
[3] http://www.hcinema.de/laser.htm
[5] https://commons.wikimedia.org/wiki/File:CIExy1931_Rec_2020_and_Rec_709.svg
[6] Power Technology, Inc.
[7] https://en.wikipedia.org/wiki/File:Laser_speckle.jpg

References

[1] Cruz-Neira, C., Sandin, D. J., and DeFanti, T. A., "Surround-screen projection-based virtual reality: the design and implementation of the cave," in [*Proceedings of the 20th annual conference on Computer graphics and interactive techniques*], 135–142, ACM (1993).

[2] Kresse, W. and Reiners, D., "Can we trust that image? photometric attributes of current projection systems," *VR2002 Proceedings* (2002).

[3] Jorke, H. and Fritz, M., "Infitec-a new stereoscopic visualisation tool by wavelength multiplex imaging," *Proceedings of Electronic Displays* **2003** (2003).

[4] Lotsch, H. K., "Optischer sender fuer mindestens zwei farbkomponeneten," (1963).

[5] Behr, J., Eschler, P., Frohlich, T., Knopfle, C., Lutz, B., Muller, S., and Roth, M., "Cybernarium days 2002-a public experience of virtual and augmented worlds," in [*Cyber Worlds, 2002. Proceedings. First International Symposium on*], 553–560, IEEE (2002).

[6] "Hamburg planetarium." `https://www.zeiss.co.za/vision-care/en_za/worldwide/basket/references/europe/germany/hamburg.html`. Accessed: 2017-01-10.

[7] "Vienna zeiss planetarium." `https://www.zeiss.com/planetariums/us/references/europe/westerneurope/vienna.html`. Accessed: 2017-01-10.

[8] Trisnadi, J. I., "Speckle contrast reduction in laser projection displays," in [*Electronic Imaging 2002*], 131–137, International Society for Optics and Photonics (2002).

[9] Tran, T.-T.-K., Svensen, Ø., Chen, X., and Akram, M. N., "Speckle reduction in laser projection displays through angle and wavelength diversity," *Appl. Opt.* **55**, 1267–1274 (Feb 2016).

[10] Tran, T.-K.-T., Chen, X., Svensen, Ø., and Akram, M. N., "Speckle reduction in laser projection using a dynamic deformable mirror," *Opt. Express* **22**, 11152–11166 (May 2014).

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