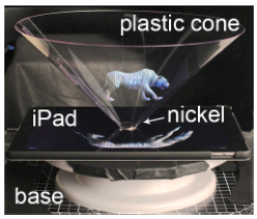
Pepper’s Cone Research

Pepper’s Cone Effect

Pepper's Cone is an innovative, cost-effective 3D display system that combines a tablet computer, such as an iPad, with a hollow plastic cone and a rotatable base. This setup allows users to view three-dimensional objects from any direction over a 360-degree path without the need for special glasses. The system is inspired by the classic Pepper's Ghost illusion, utilizing a curved transparent surface to reflect images displayed on the tablet. By pre-distorting the displayed image, the system produces a perspective-correct visualization that appears suspended within the cone, providing an intuitive interface for examining 3D scenes.

From a technical standpoint, the system leverages the gyroscope integrated into modern tablets to adjust the rendered image based on the viewer's orientation. This real-time adjustment ensures that as users rotate the display, they perceive a consistent and convincing 3D effect. The choice of a conical reflector was determined through analysis of optical performance and stereo-compatibility among rotationally symmetric conic reflector shapes. The system can also be extended to produce correct binocular cues by incorporating stereoscopic rendering and glasses, enhancing the depth perception for the viewer.



(a)

(b)

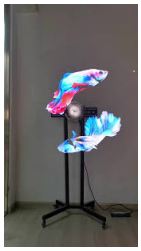
(c)

(d)

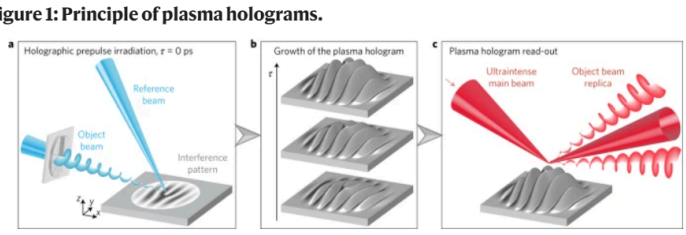
Different Types of Holograms

Musion 3D (Eyellusion / Hologauze Projection) – A high-definition holographic projection system that uses a special semi-transparent screen to create life-like 3D images. It's often used for concerts, live events, and theatrical performances, allowing for realistic digital performers to interact with live actors on stage. Examples: Disaster! queue (defunct), Harry Potter and the Escape from Gringotts pre show, Hagrid's Magical Creatures Motorbike Adventure pre show, Harry Potter and the Forbidden Journey queue, on-ride Fast and Furious - Supercharged.

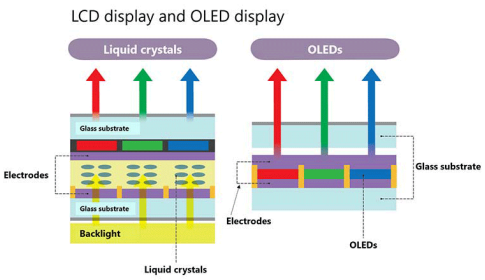
Fan-Based Holograms – These holograms use high-speed spinning LED fans that create persistence-of-vision (POV) effects. The fans display 3D visuals that appear to float in mid-air. They are commonly used for advertising, entertainment, and retail displays due to their portability and cost-effectiveness. Examples: Guardians of the Galaxy: Cosmic Rewind

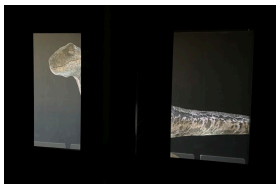


Laser Plasma Holograms – This technology projects laser beams into the air or a medium like fog, creating a true 3D volumetric image without the need for a physical screen. These holograms are still in experimental stages but hold promise for interactive applications and futuristic displays. They manipulate ultraintense laser beams by inducing holographic interference patterns on a plasma surface, creating transient phase gratings. These structures can diffract high-intensity laser pulses, generating optical vortices and high-order harmonics, offering a novel approach for laser beam shaping and extreme ultraviolet (XUV) vortex generation.



TOLED: Transparent OLED (TOLED) displays are a specialized type of organic light-emitting diode (OLED) screen that allows light to pass through while still displaying images. Unlike conventional OLEDs, which use an opaque substrate, TOLEDs use a transparent cathode and anode, enabling visibility from





both sides. These displays maintain a balance between image clarity and transparency by utilizing thin-film technology, often achieving around 70% transparency. TOLEDs are commonly used in augmented reality applications, automotive heads-up displays, and immersive entertainment experiences, where real-world objects need to be visible alongside digital overlays.

AR-Based Holograms (Augmented Reality Holography) – Using devices like Microsoft HoloLens or Magic Leap, AR-based holograms overlay digital content onto the real world. These are widely used in medical training, industrial design, and interactive gaming, providing users with immersive experiences.

Light Field Displays – These displays use multiple angles of light to create 3D visuals without the need for special glasses. They enable viewers to see different perspectives of an object depending on their position, making them ideal for medical imaging, design visualization, and entertainment.

Volumetric Holograms – These are created using multiple projectors and optical techniques to generate a fully volumetric 3D image that can be viewed from all angles. Applications include scientific visualization, medical imaging, and immersive experiences in museums and exhibitions.

Optical Illusion: Some Experiments using a Pepper's Ghost Apparatus with Double Chamber [3]

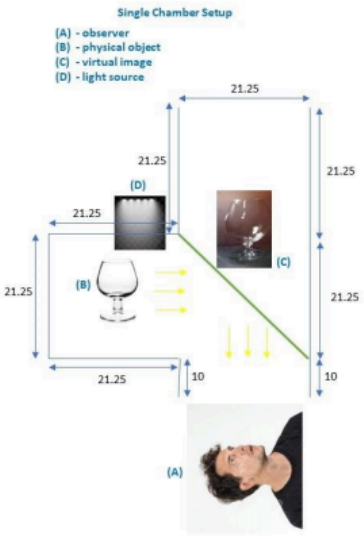
This paper explores the Pepper’s Ghost illusion, a classic optical technique used to create hologram-like effects using light reflection. The study presents an experimental setup that improves upon the traditional Pepper’s Ghost apparatus by introducing a double-chamber system, allowing for the projection of two independent images at the same time.

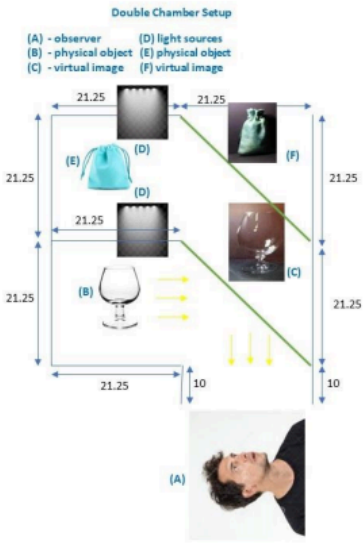
The research discusses:

- Historical background of Pepper’s Ghost, which dates back to the 19th century and was used in stage performances and later adapted for modern applications like amusement parks and concerts.
- The physics behind the illusion, including reflection and refraction principles that govern how light interacts with transparent surfaces.
- Construction of the apparatus, where the author builds a double-chamber system, utilizing commercial transparent plastic sheets at precise 45-degree angles to create a layered illusion effect.
- Experimental results, demonstrating how different objects (e.g., a cup, a bag) can appear and disappear by adjusting light intensity, and how overlapping images can be generated.

Key Findings:

- The double-chamber design successfully allows for superimposed images, expanding the illusion’s possibilities.
- Lighting control is crucial—adjusting illumination levels minimizes unwanted reflections and enhances the effect.
- Challenges such as dust accumulation and material imperfections impact illusion quality but can be mitigated with careful maintenance.





Delicious Cyber Ghost: Using Pepper's Ghost in Computer-Aided Design to Enhance Cantonese Morning Tea Education [2]

This research paper explores an innovative approach to preserving and promoting Cantonese morning tea culture using Pepper's Ghost, an optical illusion technique. The study integrates augmented reality (AR) and computer-aided design (CAD) to create an immersive educational experience aimed at engaging younger generations and revitalizing cultural heritage.

Key Themes & Contributions:

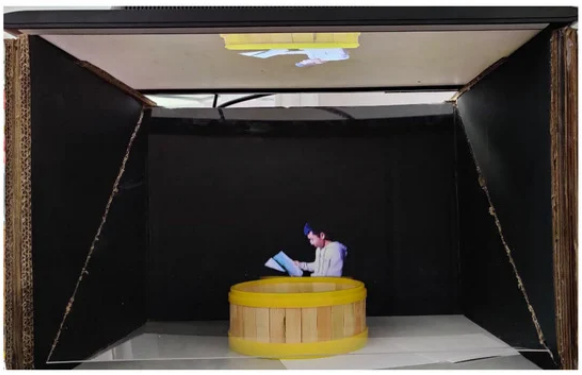
- Preserving Cultural Heritage: Cantonese morning tea (Yum Cha) is a long-standing tradition in the Guangdong–Hong Kong–Macao Greater Bay Area, but modern lifestyles and urbanization threaten its continuity. The study seeks to enhance awareness and appreciation of this tradition through digital storytelling and interactive AR experiences.
- Application of Pepper's Ghost: The researchers developed a prototype device that leverages Pepper's Ghost to project holographic-like visuals of traditional tea dishes and cultural elements. This setup enables a hybrid experience of physical dining combined with digital immersion.

Three-Dimensional Modeling & AR Integration:

- Storytelling Approach: A scripted narrative featuring a virtual character, "Shrimp Dumpling", helps explain Cantonese morning tea etiquette in an engaging way.
- Virtual & Real-World Scenes: The researchers created 3D models of tea dishes and iconic Cantonese landmarks, blending them with live performances.
- Device Construction: The prototype includes corrugated paper for framing, acrylic sheets for imaging, and a 27-inch LCD screen for display.

Key Findings:

- The AR-enhanced storytelling approach was effective in making Cantonese morning tea more engaging for younger audiences.
- Lighting control and material selection are crucial for optimizing the Pepper's Ghost illusion.
- The digital preservation of Cantonese tea culture could serve as a template for other cultural traditions.

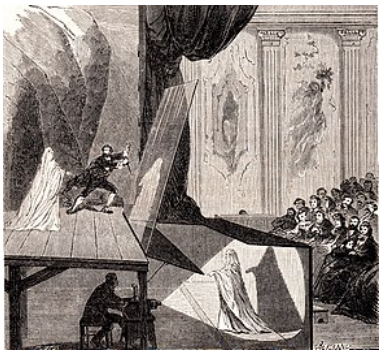


Pepper’s Ghost Research [1]

Pepper's Ghost is a classic illusion technique that creates the appearance of ghostly apparitions on stage. It involves reflecting an image of an off-stage object onto a transparent surface, making it seem as though the object is present in the scene.

Historical Background:

- Giambattista della Porta's Early Description: In 1589, Neapolitan scientist Giambattista della Porta described an illusion in his work Magia Naturalis that is considered the first known account of the Pepper's Ghost effect.
- Henry Dircks' Contribution: In the 19th century, engineer Henry Dircks developed a method called "Dircksian Phantasmagoria," which used a hidden room, a sheet of glass, and strategic lighting to project ghost-like images on stage. However, his technique required theaters to undergo significant structural modifications, limiting its adoption.
- John Henry Pepper's Innovation: John Henry Pepper, a scientist and lecturer, refined Dircks' method to be more practical for existing theaters. He showcased this improved technique during an 1862 Christmas Eve production of Charles Dickens' The Haunted Man and the Ghost's Bargain at the Royal Polytechnic Institution in London. The illusion was a sensation, leading to widespread use in theaters and securing Pepper's name in association with the effect.



Technical Overview:

The illusion is achieved by placing a large pane of glass at a 45-degree angle between the audience and the stage. A hidden room, often referred to as the "blue room," contains the object or actor to be projected. When the blue room is illuminated, its reflection appears on the glass, creating the illusion of a ghostly figure on stage. Adjusting the lighting allows the figure to fade in and out, enhancing the spectral effect.

Modern Applications:

- Amusement Parks: Attractions like Disneyland's Haunted Mansion use the technique to create lifelike ghostly apparitions.
- Concerts: The effect has been employed to project virtual performances of artists such as Tupac Shakur and Michael Jackson, often mistakenly referred to as "holograms."
- Museums and Exhibitions: Museums use Pepper's Ghost to bring historical figures to life, enhancing educational displays.

Synopsis of "Pepper's Cone: An Inexpensive Do-It-Yourself 3D Display" and GitHub [4][5]

This video, presented at the ACM Symposium on User Interface Software and Technology (UIST) 2017, introduces Pepper's Cone, a cost-effective, DIY 3D display system developed by Xuan Luo, Jason Lawrence, and Steven M. Seitz.

Key Highlights:

- Innovative Design: The Pepper's Cone leverages the classic Pepper's Ghost illusion, utilizing a conical reflective surface to project 3D images that can be viewed from multiple angles without the need for special glasses.
- Accessibility: Emphasizing affordability and simplicity, the design allows enthusiasts and educators to construct their own 3D displays using readily available materials, making 3D visualization more accessible.
- Applications: Potential uses include educational tools, interactive exhibits, and creative projects, offering an engaging way to visualize 3D content.

Image Processing & Rendering

- Pre-distorted image rendering: The system warps 3D models into a 2D form that appears normal when reflected.
- Dynamic view adjustment: The rendering system updates based on user viewing position, similar to head-tracking but without external sensors.
- Multiple Viewing Angles: Unlike typical holograms, multiple users can observe the illusion from different positions without loss of effect.

Software Pipeline

- Implemented in Unity with support for shader-based rendering.
- Uses OpenGL or DirectX for real-time perspective transformation.
  Rendering method:
    - Converts 3D model coordinates into a 2D distortion map.
    - Adjusts projection based on the cone’s optical properties.
    - Displays the pre-warped image on a tablet screen.

Hardware Requirements

- Display: Requires a tablet or high-resolution monitor.
- Cone Material: Transparent acrylic or polycarbonate sheet.
- Base Structure: Stabilization using a nickel weight or suction cup.
- Graphics Processing: A standard GPU can handle rendering, but optimizations may be needed for real-time rendering on mobile devices.

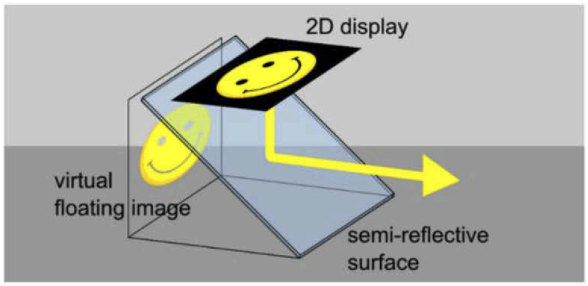
Advancing 360° Volumetric Displays with Retro-Reflective Projection Technology [6]

The article "Multi-user volumetric 360° display based on retro-reflective projection technology" presents an innovative approach to creating a true volumetric 3D display that allows multiple users to view the same three-dimensional image from any angle—without the need for special glasses or head-tracking systems. Traditional 3D and holographic displays often struggle with issues like limited viewing angles, distortion, and the need for additional hardware, making them impractical for many real-world applications. This research aims to overcome these limitations using retro-reflective projection technology, a method that ensures light is reflected back toward its original source, maintaining image consistency regardless of the viewer's position.

The display system is built around a transparent projection surface, allowing users to walk around it and observe a stable, high-quality 3D image from all 360 degrees. This is a significant improvement over conventional holographic and stereoscopic systems, which often suffer from fading or distortion when viewed from different angles. By carefully designing the optical setup and projection mechanics, the researchers demonstrate a scalable, immersive 3D visualization method that can support multiple viewers at the same time.

One of the key breakthroughs in this research is the ability to maintain image depth and clarity across different viewpoints. Many existing volumetric displays face challenges with image warping or ghosting when viewed from extreme angles, but the retro-reflective projection technique minimizes these distortions. The system uses high-precision projectors and optical elements to achieve this effect, ensuring that each viewer perceives a consistent and well-defined 3D object.

a)



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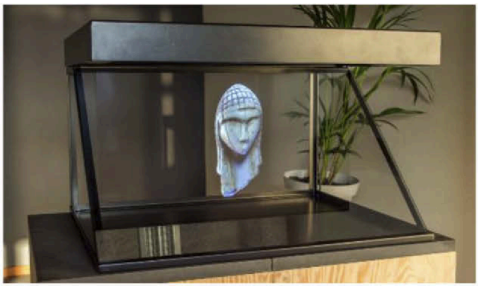


This technology has broad implications for a range of applications, including medical imaging, collaborative design, data visualization, and entertainment. For example, in medical fields, doctors could use this display to examine detailed 3D scans from all angles without needing VR headsets. In collaborative design and engineering, multiple users could interact with and analyze 3D models in real-time, enhancing workflow efficiency.

The researchers also discuss potential areas for future improvement, such as increasing display resolution, expanding scalability, and refining projection precision to make the system more commercially viable. While the current implementation demonstrates a significant step forward, further optimizations could enhance image brightness, contrast, and interactivity.

Overall, this study highlights a major advancement in volumetric display technology, addressing key limitations of traditional 3D visualization methods and paving the way for more practical and immersive applications.

Life-Size Holograms with Pepper’s Ghost: A Breakthrough in 3D Telepresence [7] [8]

The article and video titled "LIVE SIZE HOLOGRAM streamed with Pepper’s GHOST by Glimm" showcase an innovative holographic display system that enables life-size, real-time hologram projections using the Pepper’s Ghost technique. This technology allows users to see a realistic, three-dimensional representation of a person or object without the need for VR headsets, AR glasses, or other wearable technology.

How It Works

The system relies on a combination of high-resolution video streaming, specialized projection surfaces, and lighting techniques to create the illusion of a floating hologram. Unlike traditional holographic displays that require complex volumetric projection setups, Pepper’s Ghost works by reflecting a high-quality image onto a transparent projection surface. When positioned correctly, this reflection appears to be a free-standing 3D object, even though it is actually a carefully angled optical illusion.

Glimm Display's approach enhances this classic technique by incorporating modern high-definition projectors, interactive elements, and real-time streaming capabilities. This means that a person or object recorded in one location can be instantly projected as a full-scale hologram anywhere in the world, making it ideal for remote meetings, live events, retail marketing, and even telemedicine applications.

Applications and Benefits

One of the key advantages of this system is its scalability and realism. The ability to project life-size holograms means it can be used for corporate presentations, concerts, product showcases, and immersive storytelling. For example:

- Business and Conferences: A speaker from another country can give a presentation as if they were physically present.
- Retail and Marketing: Companies can showcase products in 3D without needing physical samples.
- Entertainment and Events: Artists can perform as holograms, similar to famous posthumous concerts featuring Tupac or Michael Jackson.
- Education and Training: Medical students or engineers can observe lifelike demonstrations without being physically present.

The technology also has implications for reducing travel costs and carbon footprints, as professionals can "appear" at multiple locations without physically traveling.

Challenges and Future Developments

While this method offers an immersive experience, it still has some limitations. The illusion depends heavily on controlled lighting conditions and a well-positioned projection surface, meaning it might not work effectively in all environments. Additionally, depth perception and interactivity are areas that could

be improved with future advancements, such as AI-powered motion tracking and better projection materials to create even more realistic, dynamic holograms.

Final Thoughts

Glimm Display’s life-size hologram system using Pepper’s Ghost represents a significant step forward in holographic communication and interactive display technology. By combining high-resolution video, real-time streaming, and advanced optics, this innovation makes 3D telepresence a practical and scalable solution for businesses, entertainment, and education. As technology improves, we can expect even more realistic, interactive, and immersive holographic experiences in the near future.

Explaining the Pepper’s Ghost Illusion with Ray Optics [9][10]

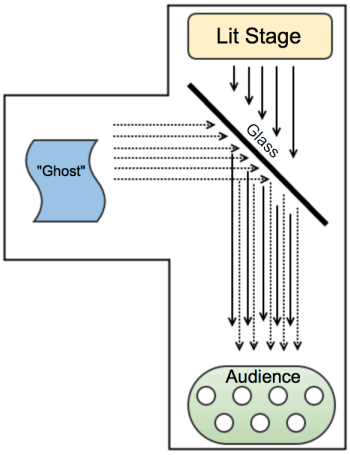
The Pepper’s Ghost illusion is an optical technique that creates the appearance of a floating, ghostly image by manipulating light reflection. While often mistaken for a hologram, the effect relies on ray optics principles, using a transparent reflective surface to superimpose an image into a viewer's line of sight. This technique is widely applied in theater, theme parks, digital projections, and even augmented reality (AR) displays.

How the Illusion Works

At its core, the illusion is based on the partial reflection and transmission of light. The setup typically includes:

- A transparent surface (glass or acrylic) positioned at an angle.
- A primary scene visible to the audience.
- A hidden image or video projection that is reflected onto the transparent surface.

When light from the hidden image hits the glass, a portion of it reflects toward the audience, merging with the main scene. By adjusting lighting conditions, the illusion can be strengthened or faded out, making the hidden image appear and disappear.



Ray Optics Breakdown

The illusion follows basic reflection and refraction laws:

- Light travels through different media (air, glass) with varying refractive indices.
- When it encounters the angled transparent surface, part of it is transmitted, and part is reflected.
- The audience perceives both the real scene and the reflected image, causing the illusion of a floating figure.

The Fresnel equations govern how much light is reflected or transmitted, depending on the angle of incidence and the materials used.

Modern Applications

Over time, the Pepper’s Ghost technique has evolved into a more advanced version, incorporating video projections and digital effects. A notable example is the 2012 Coachella music festival, where a digital recreation of the late rapper Tupac Shakur performed on stage. This was achieved using a high-resolution video projection onto a transparent film, simulating a realistic hologram.

Tupac Hologram Snoop Dogg and Dr. Dre Perform Coachella Live 2012

Additionally, museums, concerts, and advertising displays use similar technology to create immersive experiences. Some modern variations involve 3D computer-generated imagery (CGI) and augmented reality (AR) applications to produce realistic holograms.

Pepper's Ghost Illusion in a Small Space [11]

Theoretical Framework: Light Reflection and Optical Constraints

The illusion relies on partial reflection through a transparent material such as plexiglass or Lexan. Light from an image source—typically a projector or screen—is directed at a reflective surface. When positioned at an optimal angle (around 45 degrees), the transparent surface reflects this light toward the viewer while still allowing visibility of the background. The result is a semi-transparent floating image that appears to be integrated into the scene.

However, in smaller spaces, certain limitations arise:

- Viewing Angles – The audience’s perspective must be carefully controlled to ensure the reflected image aligns correctly with the real environment.
- Projection Distance – The size of the projected image depends on how far the source is placed, requiring precise scaling to fit within confined spaces.
- Lighting Conditions – Ambient light can interfere with reflections, necessitating controlled darkness to enhance the ghostly effect.

Optimizing the Setup for Small Spaces

Material Selection and Spatial Adjustments

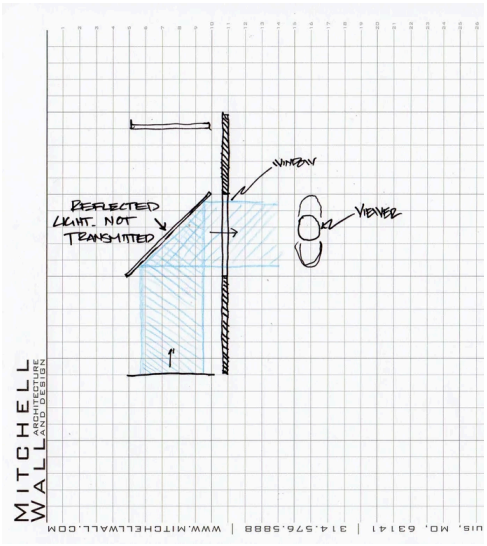
Unlike large-scale implementations, where glass panels are commonly used, small-scale adaptations require lightweight and cost-effective alternatives like plexiglass or Lexan sheets. These materials offer similar reflective properties while being easier to install in limited environments.

Projection and Reflection Adjustments

To achieve the illusion in a restricted space, a dual-reflection setup can be employed:

- A mirror is placed to reflect the projected image onto the transparent sheet.
- The transparent sheet then redirects this image toward the viewer.

Additionally, enhancing the projection surface—such as using a white backdrop to increase contrast—improves image visibility without requiring additional space.



Reflection and Light Behavior in the Pepper’s Ghost Illusion

The diagram below illustrates how plexiglass functions as a reflective surface in the Pepper’s Ghost illusion. Instead of allowing light to pass through, the plexiglass reflects the projected image toward the viewer. This phenomenon is based on the principle that reflected light is more visible than direct light transmission.

A practical analogy is how sunlight affects visibility—on a bright day, objects around us are easily seen, but looking directly at the sun is difficult due to its intensity. Similarly, in this setup, the observer perceives the reflected image more clearly than the original light source, enabling the ghostly effect central to the illusion.

Appendix

[1] “Pepper’s Ghost,” Wikipedia, [Online]. Available: https://en.wikipedia.org/wiki/Pepper’s_ghost (accessed Mar. 13, 2025).

[2] S. Xu, P.-W. Hsiao, C. Li, and J.-Y. Zhang, “Delicious cyber ghost: Using Pepper’s Ghost in computer-aided design to enhance Cantonese morning tea education,” IEEE ICEIB 2024, p. 78, Nov. 2024. DOI: 10.3390/engproc2024074078.

[3] “Optical Illusion: Some Experiments Using a Pepper’s Ghost Apparatus with Double Chamber,” ResearchGate, [Online]. Available: https://www.researchgate.net/publication/368274915_Optical_Illusion_Some_Experiments_using_a_Pepper’s_Ghost_Apparatus_with_Double_Chamber (accessed Mar. 13, 2025).

[4] YouTube Video: ACM SIGCHI, [Online]. Available: https://www.youtube.com/watch?v=dppCXj11I_Q&ab_channel=ACMSIGCHI (accessed Mar. 13, 2025).

[5] Roxanneluo, “Pepper’s Cone - Unity Project,” GitHub, [Online]. Available: https://github.com/roxanneluo/Pepper-s-Cone-Unity?tab=readme-ov-file#demo (accessed Mar. 13, 2025).

[6] Z. Pan, Y. Yuan, Z. Li, C. Yang, Y. Wu, and S. Liu, "Multi-user volumetric 360° display based on retro-reflective projection technology," Optics Express, vol. 28, no. 26, pp. 39524-39538, Dec. 2020. [Online]. Available: https://opg.optica.org/oe/fulltext.cfm?uri=oe-28-26-39524&id=444799.

[7] B. Bijster, "LIVE SIZE HOLOGRAM streamed with Pepper's GHOST by Glimm," Glimm Display, Jun. 15, 2021. [Online]. Available: https://www.glimmdisplay.com/live-size-hologram-streamed-with-peppers-ghost-by-glimm/.

[8] YouTube Video: Glimm Display - Live Size Hologram, [Online]. Available: https://www.youtube.com/watch?v=EH71Y2RE1IM (accessed Mar. 13, 2025).

[9] Explaining the Pepper’s Ghost Illusion with Ray Optics, COMSOL Blog, [Online]. Available: https://www.comsol.com/blogs/explaining-the-peppers-ghost-illusion-with-ray-optics (accessed Mar. 13, 2025).

[10] YouTube Video: Tupac Hologram Snoop Dogg and Dr. Dre Perform Coachella Live 2012, [Online]. Available: https://www.youtube.com/watch?v=TGbrFmPBV0Y (accessed Mar. 13, 2025).

[11] Pepper’s Ghost Illusion in a Small Space, Instructables, [Online]. Available: https://www.instructables.com/Peppers-Ghost-Illusion-in-a-Small-Space/ (accessed Mar. 13, 2025).