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Haptic Holograms: The Liminal Communication of Emerging Visio-Haptic Apparatuses

JASON EDWARD ARCHER♦
Michigan Technological University, USA

THOMAS CONNER[1]
The University of Tulsa, USA

This article interrogates the development of two technologies that have started to converge—midair haptics and holograms—and theorizes that their combination disrupts notions of visuality, touch, and communication. Drawing from three articulations of haptics and Vilém Flusser's philosophical concept of the "technical image," we argue that three-dimensional rematerializing does not mean turning a representation "back" into its object but rather into a different kind of representation. Just as viewing a digital image means viewing a computed abstraction, so does touching what these systems calculate and produce *as* a surface. The resulting new experiences are of something *other* than a hologram or even an image—they are unique liminal spaces for the production and experience of new cultural objects, ways of knowing, and modes of communication.

Keywords: haptic media, visual culture, computation, media technologies, epistemology

The word "hologram" has been applied to two distinct technical objects: Optical holograms and digital projections. Both are visual images—*technical* images, defined by Vilém Flusser (1984) as imagery created and computed by machines rather than made by hand—that are produced for passive viewing by spectators. This article, however, analyzes several cases of systems producing technical image-objects that attempt to enhance the material aspect of imagery by affording digital holograms with tactility to deliver representations that may be both viewed *and* touched. That is, when one touches a drawing, painting, or a screened image, they touch the two-dimensional (2D) medium of the canvas or screen; emerging haptic holograms attempt to dissolve the experience and even awareness of physical media by affording spectators the opportunity to look at an image and then touch the represented object rather than the medium representing it visually. We first theorize about relationships between real-world technical development and science-fiction thought experiments, which we follow up

Jason Edward Archer: jearcher@mtu.edu
Thomas Conner: tconner@ucsd.edu
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[1] Equal authorship with first author.

by drawing out elements of recent projects that attempt to realize the sci-fi imaginary of physically touching holograms.

Optical holograms are produced using a complex imaging process similar to photography, in which the diffraction pattern of two sources of coherent light (lasers), one of which reflects off an object or subject, is recorded on a photographic plate; when that plate is again illuminated, the precise three-dimensional (3D) image of the object or subject is "replayed," so an actual 3D image appears floating in midair behind or in front of the plate. By contrast, digital holograms are computed, often animated imagery, usually projected onto invisible screens in proportion to their environment to simulate 3D qualities, appearing to be physical objects or subjects occupying the real space of their spectators. The use of veiled screens for the presentation of the imagery allows spectators to see the visuals without the need for special glasses or other equipment—an augmented-reality (AR) technology rather than a virtual-reality (VR) technology.

Regardless of whether it is produced by optical actuality or digital simulation, the 3D-ness of holograms complicates the traditional passivity of the spectator. The viewing subject of holograms often tries to reach out and touch the image. Previously, spectators had failed in this effort—in the case of real, optical holograms, the viewer's hand would strike nothing solid (unless knocking against the frame); in the case of digital holograms, the viewer would strike the invisible screen (and indeed be startled by its thus-far unnoticed presence). Newer technologies attempt to satisfy this reaching effort. "Haptic holograms" combine felt feedback with holographic imaging to deliver a sense of touch during an encounter with 3D imagery. Haptic feedback is the production of physical feedback using mechanical, electrical, computational, chemical, or other means to provide a touch-based interaction within a virtual or digitally augmented environment. The addition of this form of feedback to a system that also produces hologram imagery means that users can both see a 3D image as well as reach out and touch it—feeling an object's represented texture, boundaries, and borders, or a combination of these. The futility of the traditional holographic gesture is eliminated, and digital imagery moves one step closer to actualization in the dimensional, physical realm.

But what is produced through the design of this technical feedback? In this article, we interrogate prototype systems that seek to converge haptics and holograms because we argue that they challenge notions of visuality, touch, and communication in interesting, important, and timely ways. The objects of our analysis are three specific types of holograms that have been developed not only to do what holograms have usually done, which is to present and project a 3D image of an object within a spectator's real space but also to add some degree of ability to touch that image as if it were an object—essentially further mixing up ideas, representations, experiences, and ontologies about images and objects.

Our intent is to consider these cases of haptic hologram systems within the separate theories surrounding both holography and haptics and to propose questions for existing and future research about the confluence of these two projects. In each published study, the researchers pose relevant questions and intriguing speculations about the practical and commercial potential of their systems. We, however, seek to extend the theoretical consideration of these technologies to include inquiries about their media effects, phenomenological experiences, and social provocations. For instance, what are we touching when we touch holograms? Significant theories from phenomenology to material visuality are foregrounded in these projects. Furthermore, what are we touching when we touch *haptic* holograms? The spectator in these cases

is often led to believe they are touching, say, a cube or a ball, when in fact they are touching a particular technical system's programming for the production of a sensation resembling the surface of a cube or a ball, respectively. When touch is thus re-centered within the design of technical media, how is human communication being reimagined?

Previous theories about holograms have suggested that their 3D-ness nudges them toward something more than mere imagery; however, because they had not been considered or experienced previously as full objects in and of themselves, they had fallen short of complete participation in theories and literatures related to presence and materialism. Does a haptic hologram finally bridge this divide, or does a continuing tension between holographic spectrality and material objecthood advance the project in a new direction? In the end, we argue that haptic holograms introduce a radical and novel experience to mediated communication and that they expand opportunities for phenomenological experience and meaning making.

From Real-World Holograms to Sci-Fi "Holograms"

Haptic holograms may not enter the mainstream anytime soon, but they still create space to think about holograms and haptics, vision, and touch in generative ways that also may challenge current conventions. Drawing on the works of Flusser (2014, 2015), cinema scholars, and haptic media scholars, it becomes clear there are several overlapping ways to approach haptic holograms that situate them as ontological, phenomenological, political, and cultural objects. Our intention is to identify such sociocultural provocations that are created by these emerging systems and by the overall project of haptic holography.

Claims made by researchers in labs, especially regarding haptics, should be met with some skepticism given the field's historical failure to live up to its claims, an issue David Parisi (2020) identifies as the perpetual immanence of haptics. This is something of a hangover from the seemingly limitless future of human-image interaction promised by sci-fi narratives, especially in TV and film. Indeed, any consideration of emerging real-world digital hologram systems must be foregrounded by the now-dual history of optical holography development and display in the real-world and fictional depictions of social desires for such technologies that became omnipresent throughout the experimental laboratory of science fiction. As cultural narratives tend to do, the *Star Wars* and *Star Trek* sci-fi franchises, for instance, trained generations of spectators in what to expect from holographic encounters.

A common instinct to reach out and try to touch 3D imagery has been observed since the earliest exhibits of optical holograms. Holography was theorized and actualized within the realm of physics in the 1940s and 1960s (Gabor, 1948, 1949; Leith & Upatnieks, 1962, 1963, 1964), but by the early 1970s, communities of hobbyists and artists began using holographic processes (Benyon, 1992; Johnston, 2016; Schröter, 2014; Zec, 1989). Institutions such as the Museum of Holography (MoH), which opened in New York City in 1976, showcased the emerging aesthetic properties of the image form. A study of texts published by the MoH and instructions posted in its galleries found that calls to "reach out and touch" the imagery were common means of activating more of the viewing subject's body in the experience of these radical visuals (Conner, 2021). The point of such discourse was not so much to initiate the reaching out but merely to assure spectators that such participation was allowable. Museum texts and especially news media reporting of hologram exhibits are pervaded by descriptions of spectators routinely reaching out toward a projected "real" hologram (an image that appears to hover in front of the holographic plate) and finding

only air or into the projected space of a "virtual" one (an image that appears to exist behind the plate) and knocking hands against the plate. One newspaper reporter marveled that a hologram "is so mystifying, viewers will be tempted to reach out and touch it. Museums consider fingerprints on the glass-covered pieces a sign that the show is being appreciated, but viewers are asked to touch gently" (Barbosa, 1980, para. 9). The language of temptation in such discourse frames the embodied act of the reach as an essential, instinctual human response—a haptic attempt to verify the solidity or spectrality of the imaged object. The MoH roundly encouraged this gesture. Study notes for the MoH's first retrospective of its collection, for instance, explain that, in Rick Silberman's hologram *Ball and Jacks*, "the projected ball is most dramatically in evidence if one moves from side to side and tries to touch it" (Anonymous, 1978, pp. 3–4). Such texts pushed spectators toward the extrasensory practice, often framing it as knowledge production: "Feel free to touch. It is part of the learning experience to see your hand go through the images and be able to understand that they float in space" (Anonymous, 1978, p. 4). Either way, the attempt to touch a hologram added interest to the spectacle of an MoH exhibit—even when that attempt would inevitably fail.

The attempted reach by a viewing subject within a holographic context is symbolic of what Vilém Flusser (2014) might have called the gesture of holography. At the time of his death in 1991, Flusser had nearly completed a thorough theory of gesture, encapsulated in a collection of essays, *Gestures*, containing 16 phenomenological descriptions of a wide range of fundamental human activities. For Flusser (2014), a gesture is "a movement of the body or of a tool connected to the body for which there is no satisfactory causal explanation" (p. 2). This movement is symbolic of "states of mind"; "it represents something, because it is concerned with a meaning" (Flusser, 2014, p. 4). Involuntary bodily movements, such as squinting in bright light, are not gestures. The gesture materializes abstract thinking and "expresses a freedom" (Flusser, 2014, p. 163). Spurred on largely by Husserlian phenomenology, Flusser's (2014) gesture is a performative projection of a specific intention. (Flusser's inclusion of both specific intention and lack of causation in his definition of gesture can be confusing. We interpret this performatively: The intent of a gesture may seem to lack causation because it is often restored behavior previously learned. This corresponds to our claims that sci-fi depictions of fictional holograms have trained spectators in how to interact with real-world ones.) In the chapter "The Gesture of Making," Flusser (2014) suggests that a tendency toward binaries in human thinking stems from the experience of possessing two hands, so that "the structure of our hands demands that the gesture of making strive for wholeness ('perfection') but also forbids ever reaching it" (p. 33). Optical holograms would seem to constitute what Flusser (2014) decides to set aside from this gesture as "incomprehensible objects," those which cannot be grasped because they are impenetrable or because "what the hands are reaching through is only air" (p. 35). "When this happens," Flusser (2014) continues, "the hands perform entirely different gestures that are not within the scope of this essay. But it is advisable to remain aware that there are incomprehensible things and that our hands cannot grasp everything" (pp. 35–36). Hologram encounters, then, manifest a novel experience with what Flusser (2015) calls "immaterial culture." Importantly, this is a phenomenological, more than an ontological, distinction. A technical image such as a hologram is experienced as immaterial despite having significant and even visible material support; however, unlike the physically inscribed, manipulated surfaces of traditional images, technical images embody an experience with technical media that makes more visible its immaterial and even idolatrous aspects, thus offering a new mode for making meaning and a postmodern episteme that Flusser (2015) suggests is a radical new mode of communication in a lengthy process of continuing emergence.

These cases and many like them attempt to add something to the medium of holography that has been traditionally denied to it. If holograms, by virtue of their spatial appearance, trigger a gestural response in spectators—an impulse to reach out and touch (and one, per Flusser [2014], that is imbued with cultural meanings)—then adding haptics to holograms attempts to close the circuit, producing a felt encounter with an apparition. But this desire is not just produced by the appearance of the hologram; it is affiliated with the cultural project of haptics, as detailed below. To paraphrase David Parisi from an interview with Allie Mularoni (2018), a media studies researcher and educator at Western University, as an industry, haptics positions itself as a response to discourses about digital objects being inherently ephemeral, therefore "we'll see haptics become part of a countertrend back to rematerialization, where touch technology will be used to give virtual objects an apparent physicality" (para. 28).

That countertrend has been precisely the discourse of sci-fi screen narratives for nearly 45 years. As speculation about optical holography's cultural potential began outrunning the technical capabilities to actualize it, the concept shifted into the theoretical laboratories of science fiction. There, holograms became "holograms"—changing from actual 3D replays of reflected light into an imaginary of 3D objects calculated by computers and projected coherently into real space. Speculative novels, films, and television narratives long have featured humans interacting with and often living among subjects that are technical image projections of digital systems and artificial intelligences—nonhuman humans, who resemble actual holograms in their spatiality and spectrality but are positioned within technical systems quite differently—but such depictions have increasingly proliferated from the 1970s onward. In these emerging portrayals of human-hologram interaction, any uncanniness or hallucinatory power is downplayed, if not erased, so that science fiction's computerized hologram becomes mythologized as an utterly natural figure—a socially sanctioned subject despite its programmed production by a veiled apparatus—acting and socializing with similarly modern, mobile, media-savvy human subjects.

The point at which a public concept of an actual hologram transmuted into an imaginary "hologram" within Western pop-cultural consciousness can be pinpointed precisely. It occurred during two scenes early in the original *Star Wars* film (Kurtz & Lucas, 1977)—scenes that depict an entirely new idea of what a hologram might be (or become) and that introduce a new imaginary about how such radically novel imagery might function within societies. The original *Star Wars* blockbuster film (Kurtz & Lucas, 1977) is a space opera set famously "a long time ago," yet its technical aesthetic is commensurate with the futurism typical of sci-fi spectacles. When the audience is first shown a "hologram" in *Star Wars* (Kurtz & Lucas, 1977), the technical image is indeed something altogether different than optical holograms, in terms of both its production method and the appearance of its resulting imagery. It is not a scientific object, per se, nor is it overtly aesthetic. The initial "hologram" of *Star Wars* (Kurtz & Lucas, 1977) is a mundane communication device, a cumbersomely delivered iteration of an enhanced video-mail message from the movie's damsel in distress, Princess Leia Organa.

In addition, this 3D message is little more than extra-dimensional video-mail—a one-way communication from sender to receiver (not unlike the production and display of aesthetic imagery at the MoH around the same time). As the *Star Wars* franchise developed, holograms became more two-way, interactive, and "live," culminating in the "force projection" of the final trilogy. For instance, in *The Last Jedi* (Kennedy, Bergman, & Johnson, 2017), Luke Skywalker, using a quasi-spiritual technique, manifests a proportional, 3D image of himself at a great distance—an image that is visible to not only spectators within

the space but also a physical agent within it, actively interacting, communicating, and fighting with others in the scene. Force projection is a spiritual rather than a technical phenomenon, but it is understood similarly within the context of the films as a spectral image that acts within the physical, social world of humans. It is this narrative arc from holograms as visibly mediated communication imagery to seemingly unmediated interactions with objects and subjects that shapes the goals for haptic projects we consider here.

The key to such narratives—and their successful positioning of hologram objects and especially subjects within depicted social spaces—is the solidity afforded to sci-fi holograms via technical magic. The *Star Trek* television franchise has followed a similar narrative arc in depicting holograms first as visibly mediated mundane communications technology and later as radical ruptures within human-computer relationships. The first episode of *Star Trek: The Next Generation* (Fontana, Rodenberry, & Allen, 1987) introduces the "holodeck," a complex technical stage in which the environment and its characters are entirely projected by computer throughout the space. Numerous early episodes feature characters marveling at the vividness of the experience, largely because of the solidity of the projected objects and subjects. Later depictions of hologram characters in the franchise include the use of holograms as deception, such as in the "Unification II" episode of *Star Trek: The Next Generation* (Berman, Piller, & Bole, 1991). In this episode, an enemy's computer system is hacked to project three human "holograms" that distract some alien captors. In these cases, the materiality of the "hologram" is controlled by the user of the apparatus programming the image. As future *Trek* narratives begin evolving the imagery from objects toward subjects, the "hologram" characters themselves (driven by artificial intelligence) gain control over their materiality.

The spin-off series *Star Trek: Voyager* (Berman, Piller, Taylor, Braga, & Biller, 1995–2001) features a hologram as a main character: The ship's acting physician, first introduced as a technical object (the Emergency Medical Hologram) and then slowly integrated as a full-fledged member of the ship's crew. Here, solidity not only allows the holographic character to function in his material duties as a doctor but also affords him opportunities to participate in social life—by swiftly acquiring a name (well, The Doctor) and becoming viewed by other crew members as something other than merely instrumental technology. Early in the show's first season, a lieutenant struggles to understand the idea that the Doctor hologram is a social agent rather than a merely visible image. The Doctor instructs the lieutenant to slap him. The possession, or at least the suggestion, of solidity and haptic engagement transforms this technical image into a technical subject—a hologram one may pat on the back, shake hands with, and include in a kind of social proprioception, being physically aware of the position and movement of its solid body in the spectator's same space.

Other examples proliferate throughout visual science fiction showing digital holographic projections used in everyday situations without undue awe at the radical magic of the technology—for example, the iconic airborne, hand-swept screens of *Minority Report* (Molen et al., 2002). The haptic holograms emerging today attempt to realize some of this same speculated solidity from sci-fi holography—but without the far-fetched magic of TV narratives. Nonetheless, as we will show, the project of haptics maintains its own imaginary.

Haptic(s)

To further understand the relationship between hapticity, visuality, and haptics, and the ways they may inform our understanding of haptic holograms, it is necessary to integrate two dominant strands of media theory into this emerging context of haptic holograms. First, we briefly consider the way that hapticity—as a cultural concept—has been transported through art history, film theory, and medium theory to articulate the potential tactile qualities of visual media (Lant, 1995; Marks, 2000; McLuhan, 1994; Sobchack, 2004). Second, to contextualize attempts to solidify the spectrality of holograms with emerging haptic technologies, we briefly consider the longer history of haptics as the "doctrine of touch" meant to make the sensitivity of the body knowable in ways that could inform the development of touch-oriented communication technologies (Parisi, 2018). Both conceptual approaches contextualize emerging developments in haptic holograms and provide useful theoretical orientations to aid our analysis. Finally, we introduce a recent history of haptic holograms, which are enjoying a resurgence with new technologies, and demonstrate that these emerging media forms are not without precedent—in both the real and sci-fi worlds.

Haptic Visuality

The concept of haptic visuality was popularized by Laura Marks in her 2000 book, *The Skin of the Film*, which sought to theorize a cinematic experience that evoked sensory responses through optical representations. However, notions of haptic visuality can be traced back to Alois Riegl's (1901/1985) use of the term "haptic" within art history (Lant, 1995). A reductive version of Riegl's (1901/1985) account, which attempted to juxtapose ideas of phenomenology and perception with cultural movements in the art world by comparing Egyptian and Late Roman art, suggested that the "shallow spatiality of Egyptian art, while optic" emulated a tactile encounter with the artwork because the perception of the encounter was registered perceptually as touch rather than vision (Sæther, 2020, p. 202). In an inversion, part of what makes television tactile for McLuhan (1994) is its ability to bombard the eye of the watcher. Riegl's (1901/1985) idea of the haptic as associated with vision and art influenced cinema theorists like Noel Burch and Antonia Lant. According to Lant (1995), Burch's (1990) concept of the haptic "is clearly tied to a conviction of spatial illusion, such that a viewer believes he or she could touch the photographic objects and actors" (p. 71). This illusion, for Burch (1990), turns the visual encounter into a touched encounter, not because the viewer *can* touch the object but precisely because they can imagine the tactile qualities of those objects that *could be* touched—hapticity experienced through evocation. Lant's (1995) concept of "haptical cinema" calls on Riegl's (1901/1985) understanding of the haptic to make sense of early cinema, equating it with the flat textuality of Egyptian art. In further developing the link between moving images and the evocation of felt memories, Sobchack (2004) suggests that the inability to literally touch objects on a screen invites a "sensual desire" that frustrated at its inability to experience objects in the film, turns the grasp onto a "more literally accessible sensual object" of ones "own subjectively felt lived body" (pp. 67–68).

The incorporation of the haptic in relation to art history and media theory offers a rich concept for considering the phenomenological, cultural, and political stakes of still and moving images. Each theory offers explanations for the desire to touch holograms even though they were not conceptualized with holograms in mind. Burch's (1990) conception of the haptic, articulated by Lant (1995), offers the clearest connection concerning the drive to touch holograms since the hologram emulates physical objects in a space

that is unmoored from the 2D screen, altering the relationship between the image and the observer. However, in a paradoxical sense, the haptic hologram may fail to produce the haptic spatiality that Burch (1990) identifies as the feeling that is produced by haptic devices is decoupled from the evocative encounter imagined by the observer—breaking the illusion necessary in Burch's conceptualization.

Haptic as a concept in art history and media theory provides useful ways of thinking about haptic holograms, but it is often framed as a form of synesthesia, uncritically creating connotations that consolidate everything resistant to the hegemony of vision with that of touch. The conceptualization also denies the possibility of a physically felt haptic encounter with the visual object. With regard to these formulations, Parisi (2018) states that,

> "Haptic" functions consistently as a strategy of sensory dedifferentiation, providing a means of breaking down the barriers between the senses and endeavoring to show how touch can be active as an agent in the process of seeing. As it did in Riegl's formulation, "haptic" serves a strategic and ideological function in these works [. . .] In these strands of thinking, the haptic conjures a counter hegemonic perpetual subjectivity activated through vision. (p. 35)

What is happening with haptic holograms cannot be reduced to haptic visuality and needs to be analyzed additionally by positioning it in relation to haptics as the "doctrine of touch" (Titchener, 1901, p. 441). The addition of haptics to holograms, in "fleshing" them out, challenges the limits of theories associated with haptic visuality because materializing the image object shifts the haptic encounter from the "subjectively felt lived body" (Sobchack, 2004, pp. 67–68) associated with prior embodied experience to an emerging experience that takes shape between the newly physicalized hologram and toucher-observer. Simultaneously, the potential disruption caused by the disconnect between expectations of what a haptic hologram should feel like based on its visual representation versus what it actually feels like based on its haptic representation is at least partially accounted for by theories of haptic visuality.

Haptics

The long history of haptics research influences the material development, phenomenological experience, and cultural implications of haptics used in the latest iterations of haptic holograms. While it is not in the scope of this article to trace the full history of haptics, which has received thorough treatment by others (Grunwald, 2008; Parisi & Archer, 2017; Paterson, 2007; Stadler, 2022), referencing some of that work is necessary to theorize the current moment in haptic development related to holograms and also provides ways of accounting for how emerging haptic holograms generate phenomenological breaks and novel cultural formations rooted in psychophysical and computational projects.

In his 2018 book, *Archaeologies of Touch*, David Parisi credits Edward Bradford Titchener, an experimental psychologist with bringing, as he states, "the German techniques for measuring sensation to the United States in the late 1800s" and defining "haptics as 'the doctrine of touch with concomitant sensations and perceptions—as optics is the doctrine of sight, and acoustics that of hearing'" (p. 105). Unlike notions of haptic visuality, haptics as a doctrine of touch seeks to scientifically render touch separate from other senses. The

project, as Parisi (2018) lays out, is a sociotechnical one replete with a history of experiments, institutional discourse to provide legitimacy for the project, and cultural representations. Highlighting some of the sociohistorical projects of haptics helps contextualize emerging haptic holograms.

In the 1800s, Ernst Weber developed instruments and methods in a scientific pursuit of knowledge about how individuals experienced tactile sensations and attempted to map felt distinctions on and in the body (Weber, 1996). Using a compass-like device with two sharp points, Weber developed an early threshold experiment that sought to determine the distance at which a subject could no longer distinguish the sensation between the two points, mapping the various tactile sensitivities over regions of the body. His influential experiments positioned touch as purely psychophysical (Parisi, 2011). Turning touch into a rationalist project separated it into a series of distinct subsystems (e.g., cutaneous, kinesthetics, vestibular, thermoceptive, and others)—a fracturing that allowed the sense to become instrumentalized in a way that informed subsequent attempts to use touch as a communicative apparatus.

Lamenting the lack of communication technologies designed for touch and building off the psychophysical traditions laid down by Weber, Titchener, and others, Carl Sherrick and Frank Geldard cofounded the Cutaneous Communication Lab at Princeton University in 1962 (Parisi & Archer, 2017). The lab produced a robust set of methods and technologies to communicate via touch—at least in a lab. In what was an especially productive period in the development of haptics, A. Michael Noll (1972) published a short article based on his dissertation, "Man-Machine Tactile Communication," in which he illustrated a device that allowed one "to 'feel' a three-dimensional object which exists only in the memory of the computer" (para. 1). Noll's motivations for a tactile interface, which were predicated on resisting overemphasizing the usefulness of graphical presentations of computational memory, anticipate the desire to touch what has increasingly become a graphically represented digital world.

Indeed, as virtual environments captured the imaginations of computer scientists, engineers, and the public, the growing absence of touch in virtual space and a desire to fill that void animated the development of haptics technologies meant to close the gap (Srinivasan & Basdogan, 1997). The desire to physicalize computer memory and materialize computer graphics to allow users to interact with digital data in more "natural" ways led to the development of several haptic interfaces, including large mounted systems, joysticks, exoskeletons, gloves, and pen-based displays, to name a few (Iwata, 2008). Some interfaces were paired with 2D graphical displays, like a desktop computer, while others were paired with 3D head-mounted displays. Practically attempting to fulfill the promise of Sutherland's (1965) "Ultimate Display," these interfaces were meant to allow users to interact with, feel, and manipulate objects that existed only as digital data, represented now in graphical and haptic form. The design of these devices, however, represented the physicalized experience as one limited, primarily, to forces and pressure—constructing objects as forces, contours, and densities.

Haptic Holography

Haptics recombined with visual objects, once the sci-fi imaginary of a hologram, began to inspire real-world research and development, leading to projects that attempted to actualize digital holograms that were physically situated and socially positioned in ways like the communication devices of *Star Wars* and

the embodied artificial intelligences of *Star Trek*. The low-cost and increasingly powerful computing technologies that began to emerge around the turn of this century provided new opportunities to realize technical experiences previously only depicted in speculative fictions.

An early project led by Mark R. E. Jones (1995) merged developments in holography and haptics. Jones' (1995) project illustrated the potential of using computer-controlled tactile gloves to interact with a reflective transfer hologram. A proof-of-concept project, it does not appear to have exited the lab. Likewise, a project led by Wendy Plesniak with Ravikanth Pappu (1998) of the spatial-imaging group in the Massachusetts Institute of Technology (MIT) Media Lab used a version of the PHANToM, a force-feedback stylus system designed at MIT, to explore the possibility of creating physical materials that could be reprogrammed, reconfigured, and rearranged in the same way that bytes were infinitely manipulatable in the computational architecture of a computer (Figure 1). Culminating in her dissertation thesis, Plesniak (2001) developed three different programs—Touch, Lathe, and Poke—that allowed users to physically manipulate the holographic image while feeling resistance from the same image through the PHANToM as it was touched, shaped, and poked.

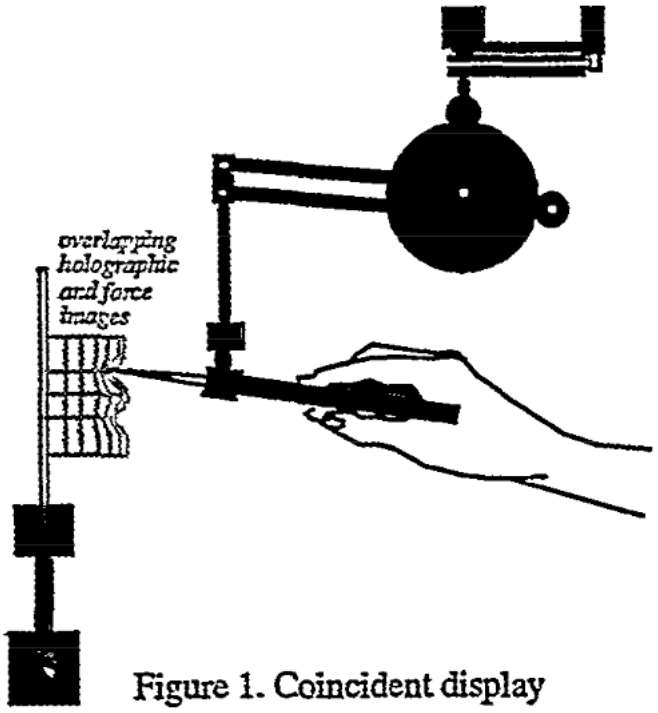

Figure 1. Coincident display

Figure 1. Illustration of how a user would use a stylus with a holographic image, shaping it and feeling forces in response (Plesniak & Pappu, 1998, p. 305).

As a medium that creates spatial illusions that invite a sense of touch and a medium increasingly capable of moving beyond tactile illusion or haptic qualities of imagery meant to usher a political response

to hegemonic norms, holograms imbued with literal physical manifestations present a convergence that pushes against easy notions of what constitutes the visual and what constitutes touch. While early haptic holograms relied on interfaces that implicated the computational medium of gloves and pens to allow the experience of touching holograms, emerging haptic interfaces—often known as midair haptics—unmoor the body from the haptic interface, erasing the device from the conscious experience of touching the hologram, articulating novel phenomenological encounters and cultural configurations.

Cases

Three specific cases of haptic-hologram prototypes recently and currently in development extend many of these concepts and actualize a few sci-fi imaginaries. The following examples work toward the same media effect of being able to produce a touchable 3D hologram though each uses different technical methods to achieve that goal. Each of these is an example of a midair system, and each applies a similar computational logic to manifest felt sensations. One produces its haptic effect via lasers, another through focused sound, and the third via concentrated bursts of air.

All three cases are *ungrounded* haptic experiences, meaning that the spectator is not constrained by any haptic device (e.g., wearables such as gloves, body plates, or headgear; or handheld devices such as pens, wands, or controllers). The ungrounded nature of the interaction creates a relationship between the spectator and the hologram image-object that may seem to the spectator to be unmediated. The absence of interface technology in contact with the spectator's body could allow the mediating technology to vanish in the visual and haptic experience, but it is not there yet. Cables, computers, and other hardware residing just out of the frames of the demos we describe in the following sections draw attention to the messy materiality necessary to produce an "unmediated" experience. Like *Star Trek*'s speculative "holodeck," these cases still present their experiences within a visible technical stage, but they are directed toward eventual prototypes and devices that will veil the mediating technology to greater degrees.

Case Number One: Laser Stimulation

The first selected case is a project using lasers, but in a markedly different way than in optical holography. Rather than harnessing the laser's illumination to create a reflected diffraction pattern, in this project, a specific kind of pulsed laser is projected into a plasma field, where it essentially draws the outline of a 3D object seemingly in midair. The laser illuminates plasma within a specific spatial field, thereby composing imagery comprised of points of light called "voxels" (essentially a 3D version of the pixels that comprise digital imagery on 2D screens). This system was created in 2015 by researchers at the University of Tsukuba's Digital Nature Group (DNG; Ochiai et al., 2015).

Combinations of lasers, mirrors, and cameras to "draw" imagery with voxels are not necessarily new though the specific kind of laser used here makes this system more plausible from a safety standpoint. Previous efforts to project 3D imagery in this way used nanosecond lasers (which pulse at the rate of one billionth of a second); these beams, however, are strong enough to burn skin (in that duration). The DNG project uses faster femtosecond lasers (which pulse at a quadrillionth of a second, in bursts that last no

longer than 270 femtoseconds) to create the voxels. The shorter duration of the laser pulses makes the image-objects safe to touch.

When a spectator reaches out with the intention to touch the seen object—for example, small hearts, fairy lights, boxes that may be checked with a "touch" of the finger—a haptic experience is generated by the laser's targeted ionization of the air, which produces a slight shock wave generated within the illuminated plasma at a precise location in space (tracked by a camera watching for the reaching fingers). A spectator then "feels an impulse on the finger as if the light has physical substance" (Ochiai et al., 2015, p. 11)—an experience that resembles sandpaper or a slight static shock (Gershgorn, 2015).

The researchers claim as chief contributions of this proof-of-concept project the comparative safety of the lasers, the significant resolution of the imagery, and the production of a haptic experience.

Case Number Two: Ultrahaptics

Our second selected case is a system that creates a haptic hologram through directed ultrasound. This system—developed by researchers at the University of Bristol's departments of computer science and mechanical engineering (Carter, Seah, Long, Drinkwater, & Subramanian, 2013)—is entirely haptic. That is, the sound waves used produce little to no visual effect, and the project is billed as one to be coupled *with* a separate visual system or used when "augmenting an interactive surface" (Carter et al., 2013, p. 506). The disturbances made by the ultrasound within a targeted field of air can sometimes be seen slightly as floating 3D shapes, and the computed haptic shapes could be visualized via an additional system, such as an AR viewer (see Kervegant, Raymond, Graeff, & Castet, 2017).

Researchers claim to be able to produce the feel of 3D shapes in midair. What they call "ultrahaptics" uses a principle of "*acoustic radiation force* whereby a phased array of ultrasonic transducers is used to exert forces on a target in mid-air" (Carter et al., 2013, pp. 505–506). Spectators reaching into this device or in relation to an interactive space encounter the sonic disturbances as a soft surface. The challenge of this type of system, particularly without the visual aid, is for users to successfully locate and identify the directed 3D shape in midair. The researchers conducted two studies with the system and reported quick learning times for users' ability to distinguish different tactile properties of simulated shapes.

This system has since been branded as UltraHaptics and acquired by Leap Motion for developing commercial applications.

Case Number Three: Air Pressure

A final example of these efforts is a project at the University of Glasgow and its Bendable Electronics and Sensing Technologies research group. In this recent experiment (Christou, Chirila, & Dahiya, 2021), a volumetric hologram is displayed using a gaming engine (Unity) to make a 2D image appear situated as if it is 3D and positioned within the available space of the device using glass and mirrors. As the spectator reaches into space, their hand is tracked by a camera and tiny jets of air are directed toward its surface and its fingers when they approach the location in space where the object is depicted.

The researchers label the experience in their experiment as "aerohaptics" and claim that it can simulate a feeling of touch. They claim to be able to create the feeling of a ball, which can be touched, as well as rolled and bounced. In addition, this system is able to "deliver haptic feedback of varying intensity" by adjusting the strength of the air jets: "large and quick movements produce a stronger haptic feedback, which corresponds to a harder hit on the ball. A more subtle movement results in a weaker air burst, replicating a softer touch to the ball" (Christou et al., 2021, p. 5).

Christou and colleagues (2021) go so far as to speculate that their concept could allow for telepresence technologies that add multiple sensory experiences in addition to the visual and auditory—that is, in addition to being able to shake hands with an absent person via this device one would be able to feel not only a surface corresponding to the situated shape of another hand but also a *warmth* similar to skin. "Apart from a touch sensation," they claim,

> air can be used to deliver other types of haptic feedback such as hot/cold sensation by controlling the temperature of the air supply. Olfactory feedback could also be delivered via this system, by introducing various scents into the air stream. (Christou et al., 2021, p. 6)

They even claim that the sound of the air jets as they deliver these other sensory experiences "may also complement the pressure and visual feedback" (Christou et al., 2021, p. 3), networking the technology's function with perceived sensory cues for a holistic perception of the encounter.

This and other aspects of the experiment, Christou and colleagues (2021) claim, make the use of air superior to systems deploying sound waves for haptic experience (as above) as well as deliver the sensations via simpler and lower-cost hardware and software. Christou and colleagues (2021) hope to expand their exploration into what they call "tensor holography" to bring the haptic experience to VR, gaming, and telepresence communication contexts.

Conclusion

In a rather poetic opening statement to *Three-Dimensional Holographic Imaging*, Plesniak, Pappu, and Benton (2002) state,

> Good holograms are bewitching. They command our eyes to their images, to search the marvelous realness of surfaces, textures, and minute detail for some aberration, some visual clue that will dissuade us from seeing as real what we know is not. Yet while they seem to assemble the very molecules of physical matter for us to ponder, they also present a conundrum: The objects they render appear frozen, lifeless, and confounding to our fingertips. What if we could render these images animate and touchable, as phantom material that was both dynamic and plastic? Such an ultimate display would be both powerful and magical; it would deliver naturally to our spatial proficiencies, inspire our imaginations, and perhaps even provoke our emotions (p. 1).

The continued development of haptic holograms moves us closer to realizing this fantastical vision, one that intersects with sci-fi imaginaries. These systems seem to be answering a call to fill a literal and metaphoric void in everyday life. By materializing images via 3D modeling in real space and physicalizing them via haptic interfaces, they offer to rematerialize loved ones or lost things, objects long forgotten, inaccessible, or that never existed to begin with—they offer a landscape for the imagination to fulfill longtime human desires to communicate with the vanished, vanquished, forgotten, and not yet formed. Imagery is empty. Touch fills the void. It is an oversimplification, but the desire to touch seems driven by a need to confirm, to control, to actualize—to touch is to believe.

What these emerging haptic experiences *do* carry over from the historical project of holograms is the liminal, spectral nature of their experience. Touch generated by these devices is unmoored from any physical interaction with the apparatus itself—which is different from the grounded haptics offered by tactile gloves and PHANToM styluses. Haptics associated with these three cases of holograms do something different—focusing solely on generating a sense of physicality to convey realness. The equation is something like: A *touchable* object (a touchable "real" hologram) is a *real* object.

But rematerializing does not mean turning a representation "back" into its object. It simply means turning it into a different kind of representation. Since the original gesture of holography did not include haptics, these new experiences are of something other than a hologram, and not even an image—something new and different entirely. This represents the pinnacle thus far of Flusser's (2015) "technical image" category, as imagery that is adept at not only producing representations of existing reality but also manifesting abstractions through programmed technologies. Haptic holograms create wholly new objects and experiences that merge into our mediated realities.

Simulations of touch merely represent existing or abstract objects, complicating representation itself through the coupling of visual and haptic experience. The touch of a hologram is thus unique. It will not feel like a ball, but it will feel like whatever a haptic hologram comes to feel like. Without the ability to materialize an image into a solid object, these systems bring computation to bear on projection not just within the visual field but along points in space where systems directly engage the gesture of holography by offering haptic feedback.

Again, a spectator does not touch the image-object but rather another part of the expanded technical apparatus: The haptic laser/sound/air system. The simulation within this sensory category merely adds another computed component to a multi-mediated system. Likewise, if the haptic experience is computed, based on a realist reproduction or a stylistic abstraction, the experience of touch is not one of an object but one native to this emerging media system. You are not actually touching fairy lights; you are touching programmed plasma. You are not actually holding a ball; you are rolling programmed air. How these emerging systems wind up situated within the map making of our shared culture will determine what uses they have for knowledge production, and maybe even new forms of culture.

Even with the illusion of edges, shape, or sensation, the continued ability for a spectator's hand to pass through the image maintains the hologram in a state of liminal spectrality—felt, at last, but without resistance, never *really* touched. Given the lack of commercial availability, accounts of what these haptic holograms feel like is lacking, but some limited evidence from encountering midair haptics without visuals

suggests people feel patterns produced as "vibration," "mild," "not natural," "unusual," "magic," "blowing feeling," "hand dryer," and "gust of wind" (Dalsgaard, Bergström, Obrist, & Hornbæk, 2022). What is felt is not the image but an expanded part of the technical apparatus: Air, sonic vibrations, lasers. This liminality of the encounter creates an interesting new space to produce new cultural objects and sensations. To emphasize this point, in a moment of marketing hype, the product manager for UltraHaptics, Charlie Alexander, said that midair haptics "allows you to create different sensations like the sensation of lightning or magic" (Arrow.com, 2018, 1:40). We do not know what lightning or magic feel like (hopefully not a "hand dryer"), but coupled with visual and textual discourse, it is possible that systems like these could determine what these things are meant to feel like (as defined by the designers). Step aside, poet—research and development is bringing touch to the untouchable!

It is difficult to predict what will happen within the field of haptic holograms. They may not live up to expectations, at least not immediately, because the haptic representations they produce will not match the depth, dimensionality, and fullness of the objects they claim to represent. In the cases we have presented—which arguably get closer to the magic Plesniak, Pappu, and Benton (2002) are describing than versions that used grounded haptics—a viewer-toucher reaches out for a hologram and feels *something*, but their reaching hand may also easily pass through that something, just as they would when reaching out for a hologram without haptics. In this case, the encounter with the hologram assumes a liminality as both a visual and tactile medium. If not rejected outright, however, this same liminality creates a generative space for new associative feelings, where the touch of an object created by the haptic hologram becomes felt as more realistic than the thing it represents—generating a kind of "haptic realism" following a path trod in photography and photorealistic art. By the same token, it also creates space for "stylized haptics" that follow the trajectory of other visual art forms. In such a space, the haptic hologram would rise to the kind of status photography and videos have with notions of realism—in which case, different apparatuses, using different methods to produce haptic sensations, would compete to become the cultural harbinger of truth when it comes to how an object is meant to feel. At the very least, haptic holograms produce a novel encounter with touch and images, physicalizing our ghostly apparitions. Perhaps that *is* a kind of magic.

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