HydrogenAR: Interactive Data-Driven Presentation of Dispenser Reliability

Preprint

Matt Whitlock,[1,2] Danielle Szafir,[1] and Kenny Gruchalla[2]

1 University of Colorado Boulder
2 National Renewable Energy Laboratory

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National Renewable Energy Laboratory
15013 Denver West Parkway
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HydrogenAR: Interactive Data-Driven Presentation of Dispenser Reliability

Matt Whitlock*
University of Colorado Boulder,
National Renewable Energy Lab
Computational Science Center

Danielle Albers Szafir †
University of Colorado Boulder

Kenny Gruchalla‡
National Renewable Energy Lab
Computational Science Center

Figure 1: HydrogenAR is a novel augmented reality application that allows for increased engagement with hydrogen fueling through participation in a simulated Hydrogen fill-up (left). HydrogenAR provides a data-driven story by situating relevant data directly in the physical environment and relative to dynamic props (right).

Abstract

When delivering presentations to a co-located audience, we typically use slides with text and 2D graphics to complement the spoken narrative. Though presentations have largely been explored on 2D media, augmented reality (AR) allows presentation designers to add data and augmentations to existing physical infrastructure on display. This coupling could provide a more engaging experience to the audience and support comprehension. With HydrogenAR, we present a novel application that leverages the benefits of data-driven storytelling with those of AR to explain the unique challenges of hydrogen dispenser reliability. Utilizing physical props, situated data, and virtual augmentations and animations, HydrogenAR serves as a unique presentation tool, particularly critical for stakeholders, tour groups, and VIPs. HydrogenAR is a product of multiple collaborative design iterations with a local Hydrogen Fuel research team and is evaluated through interviews with team members and a user study with end-users to evaluate the usability and quality of the interactive AR experience. Through this work, we provide design considerations for AR data-driven presentations and discuss how AR could be used for innovative content delivery beyond traditional slide-based presentations.

1 Introduction

Presentations of scientific concepts have historically been confined to 2D imagery, video, and text to convey a narrative to the audience. While such presentations have largely been limited to 2D screens, augmented reality (AR) displays provide an opportunity to situate virtual content directly in the physical environment. This new display media enables presentations to integrate physical infrastructure directly into the presentation narrative. In this way, AR creates an opportunity to link conceptual understanding to relevant physical components and infrastructure when presenting scientific concepts.

Previous work in virtual reality (VR) has proposed methods for unique presentations by combining flat 2D slides with 3D content [10]. This approach presents a novel design space for presentations, as presenters can incorporate 2D and 3D content and embodied interaction in a fully immersive environment. However, the notion of VR as a presentation media has only received recently received considerable research attention as the IEEE VR 2020 conference was conducted entirely online (and more major conferences to follow), with many participants attending and presenting in VR. The opportunity for novel immersive presentations is even further extended by AR, as presenters can also incorporate physical infrastructure into the narrative. As with VR presentations, research on AR presentations—particularly co-located ones—is relatively unexplored. Our work serves as a case study for using AR to integrate traditional 2D visuals with physical infrastructure, situated visualizations and 3D models and simulations to develop more engaging, interactive presentations.

Prior AR presentation systems have primarily focused on automating tour guidance to the person wearing the headset. We argue that rather than simply reducing the need for a presenter, AR presentations should consider how AR presentations should also consider how AR could be used by presenters co-located with their audiences. This is particularly important since many presentations are delivered in person via slides, videos, and images with a co-located expert controlling the pace and narrative. We therefore consider the design of guided presentations in AR, specifically focusing on how we can extend traditional, familiar presentations.

We present HydrogenAR, an application for presenting information about hydrogen fueling in a guided tour. We worked with a local Hydrogen Fuel team to iteratively design a mixed-reality system that

*e-mail: matthew.whitlock@colorado.edu
†e-mail: danielle.szafir@colorado.edu
‡e-mail: kenney.gruchalla@nrel.gov

integrates PowerPoint-style visuals with situated visualizations and an interactive fueling cycle simulation. Our design supports both the members of the team presenting and the visitors engaging with the presentation. This mixed reality approach serves to contextualize the fueling station with data and narrative and extends the existing 2D presentation to incorporate user interaction and engagement with the fueling process. We conducted a formative study that identifies benefits of this novel presentation format and future directions for AR tour and presentation research. Our work with HydrogenAR foregrounds opportunities for innovating presentation delivery in AR using novel, engaging presentation formats.

2 Related Work

Our approach the explores the benefits of using immersive AR for presentations in prior research, considering AR for tours and education, data-driven storytelling, and use of AR for information visualization.

2.1 AR Tours & Educational Presentations

Previous literature has used AR to situate virtual content in the environment for education. For example, systems have utilized AR to reveal the underlying processes in circuits to students [2]. Surgeons can perform a simulated surgery [45] or receive guidance from a remote instructor in a real operation [5]. Garzón et al. provide a systematic review and analysis of 61 AR educational studies from 2012 to 2018 and found that AR can increase student motivation [12]. These benefits of increased engagement and integration with physical infrastructure could also improve traditional 2D presentation formats.

AR has also been used as a means of tour guidance. Situated virtual content in a navigable physical environment allows users to receive automated tour guidance without a trained professional copresent. Early efforts for situated tours include the Touring Machine, which provides situated graphics outdoors to give users a tour of Columbia University's campus [9]. Situated Documentaries describe use of 3D graphics, imagery, audio and virtual flags embedded in the outdoor environment [16]. Other work on tour guidance has explored how AR might guide users through the Omaha Beach landing [25], ancient Greek ruins in Olympia [46] and indoor AR museum exhibits [50]. Commercial tools such as KreatAR [1] and Brio[2] also allow viewers to engage with 3D models at their own pace in the absence of a co-located guide. This approach is effective in delivering tour guidance when a human guide is not available, allowing the content and pacing to be personalized to the user's preferences, but does not consider use cases with a co-located presenter.

Similarly, prior work using AR has explored simulating face-to-face interaction for improved communication and collaboration, including AR for real-time remote guidance in search [33], assembly [21], medical [5], and maintenance [48] tasks. Online AR guidance allows for more instruction supported by augmentations to provide visual guidance to supplement traditional voice-only methods. Collaborative AR can also display avatars [19, 34, 51] and live holographic reconstructions of remote users [30] to enable simulated co-located meetings.

While collaborative AR research has explored these strategies of automated guidance and simulated face-to-face interaction, much less work has explored the potential for AR to improve live, co-located presentations. Zarraonandia et al. argues that a presentation should be a back-and-forth between presenter and the audience [52], in their work, exploring how AR can provide the presenter with non-interuptive visual feedback on audience understanding over the course of the presentation. Meetsu mediates communication between the presenter and audience members using an augmented video feed with annotations [6]. Commercial solutions such as Flow Immersive[3] and Prezi[4] use 3D visuals as supplemental presentation content. While these works focus on AR-mediated communication from audience members to the presenter, we instead use AR as the presentation medium. We build on this work by considering UI design for both the presenter and the audience and how physical infrastructure and situated visualizations can fit into the presentation design.

2.2 Data-Driven Storytelling

Data-driven storytelling combines visualizations with narratives to facilitate exploration and communicate information from data analyses [4, 22, 38, 44]. News organizations like the New York Times and The Economist regularly publish articles that incorporate interactive data visualizations (e.g., Rich et al. [36]). Data journalists have also been early adopters of AR [31], including through web articles [42] designed to be used with AR head-mounted displays. However, there are fewer examples of data-driven storytelling for science and engineering generally [27].

A recent survey of novel devices in data-driven storytelling notes a lack of applications showcasing data-driven storytelling in AR, despite the potential of physical props to enhance these experiences [24]. Using the multimodal input and output of AR displays, designers can craft data-driven stories that allow the audience to become immersed in the story. In the same way that visualizations embedded on a webpage supplement a journalist's narrative, we consider how situated visualization can supplement an AR presentation. Our work investigates AR as a medium for telling a data-driven scientific story contextualized in physical space on physical equipment.

2.3 Immersive Visualization

Use of immersive AR for visualization provides several benefits over traditional display media. Perhaps most notably, by displaying virtual content in a physical environment, AR can eliminate tedious context shifts that make understanding data or processes more challenging. For example, tour systems may help users navigate an exhibit by labeling points of interest and navigation cues directly in indoor [17, 28] and outdoor environments [9, 53]. Assembly and procedural instructions can be projected into the physical environment and even onto individual pieces, eliminating the need to switch back and forth between paper instructions and the task at hand [14, 15, 32]. Educational content can be retargeted to AR to provide increased context and engagement [2, 37].

In information visualization, we can leverage this reduced context switching to break down barriers in understanding data relevance through "situated visualizations." Situated visualizations can provide context to consumer data while in a store [7], express robot intent [47], and communicate the states of smart devices in an IoT-enabled smart home [11, 18]. Beyond situating visualizations in the environment, immersive displays may provide benefits to certain classes of data visualizations. Growing empirical and anecdotal evidence suggests that immersive visualization can improve data analysis in real-world settings [13]. One key reason for this improvement is the increased space to visualize data beyond that of a monitor or mobile device [1]. Multiple studies have shown an embodied perspective helps users infer depth, making it viable as a visual channel for immersive displays [8, 23, 49].

Though these immersive visualization systems provide users an opportunity to explore data in novel ways, AR has not seen as much use for presentation-oriented visualizations. In the same way journalists write articles embedded with data visualizations to portray a narrative (§2.2), so too can situated visualizations and user engagement with virtual and physical components be baked into AR presentations to provide a more engaging experience. By integrating

[1] www.kreatar.com

[2] www.experience.briovr.com/solutions/3d-presentation-software

[3] www.web.flow.gl/

[4] www.prezi.com/augmented-reality/

these visualization and storytelling components, HydrogenAR serves as a case study for use AR as a co-located presentation medium.

3 MOTIVATION

Hydrogen fuel provides a sustainable alternative to fossil fuels we commonly use to power vehicles today. Liquid hydrogen fuel offers a promising future for alternative energy as the chemical reaction within a fuel cell to generate energy results in the emission of water rather than harmful pollutants. Several challenges have inhibited widespread adoption, namely issues around producing, dispensing, and storing hydrogen fuel [43]. Our particular interest is in dispenser reliability—that in the process of compressing, storing, and dispensing hydrogen fuel, equipment failures and leaks jeopardize safety and cause considerable downtime, restricting widespread usage [20].

At the National Renewable Energy Lab (NREL), a research team focuses on issues of dispenser reliability in efforts to improve consumer fill stations. Improving reliability requires simulating aspects of hydrogen fuel dispensing that frequently cause issues. The group tests many dispensers in parallel under different conditions, such as varying pressures and temperatures, to evaluate the wear on equipment and likely failures. As with many other groups within NREL, the Hydrogen Fuel team fields many tour groups over the course of a week, ranging from public officials to potential industry partners.

They have a real hydrogen dispenser prominently positioned in the building to showcase the hydrogen fueling research conducted in the lab for passing tour groups. Unfortunately, this infrastructure currently serves as a brief talking point rather than an interactive installation to help increase understanding. We conducted an initial interview with four members of a Hydrogen Fuel team for one hour to better understand the team's goals and what their current issues are when presenting to tour groups. We then conducted follow-up interviews after two iterations of the HydrogenAR system to identify areas of improvement both for the presenter and tour recipients. In this section, we synthesize key takeaways of the team's problems and the issues around presentations and tours. We were unable to record the interviews or report direct quotes from the team due to privacy issues of working with a Government research group.

3.1 Presentations & Tours

The Hydrogen Fuel team typically makes use of PowerPoint presentations with relevant data and information to describe issues around dispenser reliability. These presentations include different types of visualizations, such as bar charts, line graphs, and box-and-whisker plots, and labeled pictures of the lab's infrastructure. Though primarily targeting consumer hydrogen dispensers, the research equipment consists of non-descript cabinets that house the infrastructure for several dispensers, compressors, and storage units. This configuration eliminates the need for a large set of fully built consumer fueling stations, but the team lamented the difficulty of contextualizing the hydrogen fill-ups within an actual dispenser. The team has set up a dispenser exhibit with two real hydrogen fuel nozzles to demonstrate what these hydrogen dispensers and nozzles look like in practice (Fig. 1). There are no presentation components on the dispenser such as labeled posters or billboards, and though the dispenser has a monitor resting on top, it is not used in any way.

3.2 Initial Design Requirements

The *Hydrogen Fuel* team (*HF*) identified key considerations for integrating AR with the existing dispenser. These design guidelines are intended for hydrogen fueling, but could also guide broader usage of AR as a presentation tool.

As the *Research Group* (*RG*), we drew on prior work in HCI and human factors to generate additional design guidelines for an immersive hydrogen fueling presentation system. These guidelines are based on own understanding and previous literature in data-driven storytelling and AR applications. Our primary goals in building the system are to provide a more engaging tour experience that better tells the intended story and to intervene with technology that would make the AR tour viable immediately as an alternative to existing tour methods.

3.2.1 Hydrogen Fuel Team

(HF1) Engage with existing infrastructure: Agnostic to any technological intervention, the team wanted to integrate direct engagement with the dispenser into tours. Given that one or more tour groups typically pass by in a given day, the team felt that integrating this physical infrastructure offered an opportunity to enhance engagement with their tour presentation; however, they lacked effective means for this integration. The biggest obstacle to integrating the dispenser was the lack of context to the broader story they were trying to tell.

(HF2) Situated reliability data: The team collects a great deal of data from their fill simulations. This data is difficult to fully contextualize within hydrogen dispenser reliability in slide form. The team sought an opportunity to better incorporate visualizations into their tour narrative. Key visualizations include the reliability of individual components and average fill profiles. We discussed the ability for AR to project visualizations such that they can render where they are relevant to help lend context to the data. As an example, they mentioned rendering data associated with a nozzle directly on that nozzle.

(HF3) Animate a simulated fill-up: The team described using AR animations to visualize the fill-up process as an important aspect for the presentation. Simulating the fill-up could help further contextualize the data the team collects in the broader story of hydrogen fueling and dispenser reliability. Since the fill takes approximately four minutes, they envisioned an experience where the user initiates the fill, is directed toward other data and key information, and is reengaged as the fill completes. They posited that engaging with the fill process and seeing it in real-time could make the experience more impactful through direct interaction with a simulation based on real data.

3.2.2 Research Group

(RG1) Simple interactions: Considering the short time frame allotted for system use, interactions should be minimal, simple, and intuitive. We use a synthesis of AR interaction design from Billinghurst et al. to inform our our own user interface [3]. One important factor is balancing adopting features from other interaction metaphors with new metaphors appropriate to the target medium. We also seek to keep the time to complete the tour low and to avoid distracting from the tour narrative with complex interactive elements or other potential sources of frustration.

(RG2) Feedback on current state: We use an AR head-mounted display (ARHMD) for its ability to project data directly onto physical infrastructure. One limitation of this approach is that the tour giver does not know what exactly the user is seeing and does not necessarily know the system state. Systems can mitigate this issue by providing feedback to the tour-giver. Though a considerable amount of literature has explored co-presence as a means of collaboration and giving a window into a user's embodied viewpoint [26, 41], our collaborators felt that simple feedback on system state and interaction success would be sufficient.

(RG3) Directed attention: The Hydrogen Fuel team mentioned that data and animations could provide beneficial augmentations to existing infrastructure. These features should carefully guide the user's attention through the tour narrative. To avoid distracting users with unnecessary information, interface designs require strategic placement of AR elements such that the tour-giver can direct attention toward them only when needed. Systems should also use animations sparingly to avoid unneeded distraction. Within the

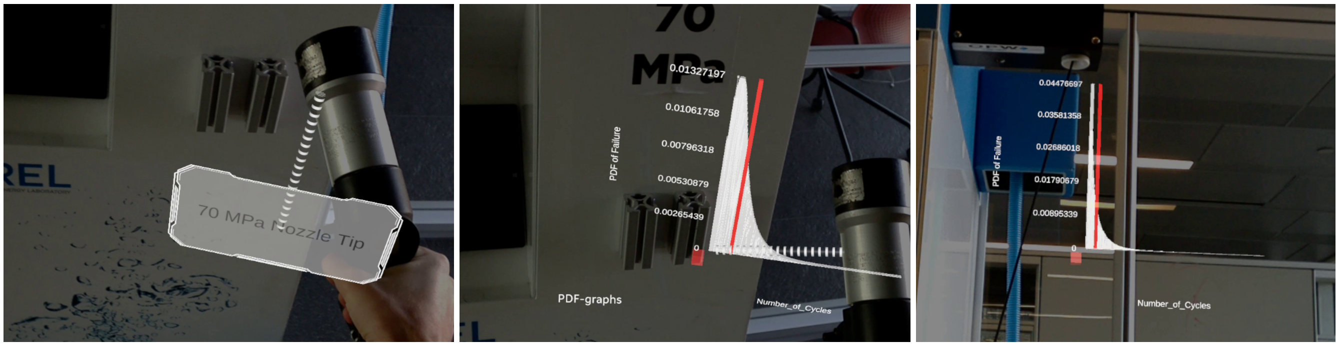

Figure 2: When the user is holding the nozzle, a semantic label of the component is rendered with a connecting line (left). The tour administer can adjust the view to display visualizations of the probability distribution of failure (PDF) for the nozzle (middle). HydrogenAR also recognizes the stationary breakaway boxes on the sides of the dispenser as points of interest with PDF data (right).

domain of data-driven storytelling, there are several ways to intentionally direct attention, including highlighting [40], animating [38], and annotating [35].

(RG4) Favor adoption over features: As a final, broad requirement that encompasses the previous *RG* requirements, we prioritize any decision that would lead to more feasible integration even if it comes at the expense of interesting features. Integration of an AR display into tours is already a fairly significant technological intervention, so any design decision should avoid increasing friction to adoption.

4 HydrogenAR System

In this section, we describe the design and implementation of HydrogenAR, a data-driven presentation tool that provides key information about hydrogen fueling to tour groups. The system delivers an interactive tour using slides, situated labels and visualizations at points of interest and an interactive simulation of a fill-up through the Magic Leap One. HydrogenAR also provides supervisory control to the tour administer using the Magic Leap One remote. We discuss the experiences for both the end-user wearing the headset and the tour administer using the remote, as well as how the system changed from feedback at different iterations of its implementation.

4.1 Tour Recipient

Tour recipients are guided through an AR experience that incorporates physical components, data visualizations, and virtual augmentations (Fig. 2). To retain familiarity and reduce the complexity of the tour experience, HydrogenAR uses traditional slide visuals to scaffold the narrative (*RG4*). Initially, the tour recipient is instructed to look at PowerPoint visuals rendered in the inlet of the dispenser as the tour administer provides an associated narrative. After motivating the hydrogen dispenser reliability problem with the initial slides, the tour recipient is guided to look at the hose breakaways, which we identify as points of interest in AR with situated text labels.

Other points of interest are at the tips of the nozzles. Using the Magic Leap One's ability to recognize hands grasping objects, HydrogenAR renders labels with a connector to points on the nozzle. We accomplish this by defining a constant (X, Y, Z) offset from the user's hand ahead of time, such that when the user's hand is recognized as grabbing a nozzle, the system understands where the tip of the nozzle is based on the hand location. For the dispenser nozzle tips, this offset was 23 cm forward (along the Z-axis) and 1 cm up (along the Y-axis) from the middle of the user's grip. HydrogenAR distinguishes between the two nozzles depending on the hand in which the nozzle is held—a nozzle held in the left hand is recognized as the 35 MPa nozzle and a nozzle held in the right hand is recognized as the 70 MPa nozzle.

In addition to semantic labels, HydrogenAR can render data visualizations of the Probability Distribution of Failure (PDF), which represents the likelihood a particular component will fail after so many cycles on top of points of interest (*HF2*). We build these visualizations using DxR [39] visualizations of the reliability data for each component. Our initial prototype rendered two labels for each nozzle—one to the tip and one to the hose outlet—as two points of interest. However, rendering the labels offset from the center of the user's field of view resulted in users looking away from their hand grasp, causing lost hand tracking. We remedied this challenge by directing users' attention towards only one point of interest on the nozzle and rendered labels and data visualizations billboarded directly in the middle of the field of view (*RG3*).

Aside from situated visualization, the nozzles are used as interaction devices to initiate a simulated fill-up (*HF1*). After engaging with points of interest on the dispenser, the tour recipient is prompted to attend to a virtual model of a hydrogen-powered car. The model is simplified to only show the overall shape, fill tank, and fuel cell (Fig. 3) to avoid overloading with unneeded components of the car (*RG3*). When the recipient touches the tip of the nozzle to the fill cap, the flow of hydrogen is initiated (Fig. 4). In initial prototypes, users had to keep the tip within a distance threshold of the fillcap for hydrogen to flow into the tank. However, for the physical nozzle to continually be recognized as being within that threshold, the user needed to hold the heavy nozzle steady in mid-air and look directly at the nozzle for the Magic Leap to recognize the user's hand. This design was both fatiguing and unintuitive, so we redesigned the fill interaction such that the initial touch to the fillcap renders a virtual nozzle on the fillcap and flow continues when the user returns the physical nozzle to the dispenser (*RG1*). We also implemented a more generous initiation threshold of 25cm, rather than the original 5cm, to account for perceived mismatches between the tour recipient's hand and the headset's perceptions of the nozzle tip and virtual fillcap. Placing the virtual model of the car behind the dispenser inherently requires the user to completely turn around, rather than divide attention between the car simulation and the PowerPoint (*RG3*).

After our initial prototype, the Hydrogen Fuel team wanted to highlight a visualization of pressure and temperature in the tour experience through a simulated car fill (Fig. 5, *HF3*). The visualization populates as a stacked line graph based on data from a simulated hydrogen fill. Once loaded, the lines turned invisible, giving the appearance of an empty visualization over the virtual car. Once the fill-up begins, line segments are added sequentially to simulate the pressure/temperature fill profile populating in real-time. A time slider at the bottom of the visualization indicates how far the 4-minute 13-second simulated fill has progressed. Throughout the fill, the color of the fill animation adjusts from white to blue based on the temperature of the hydrogen fuel at that timestep. The tank

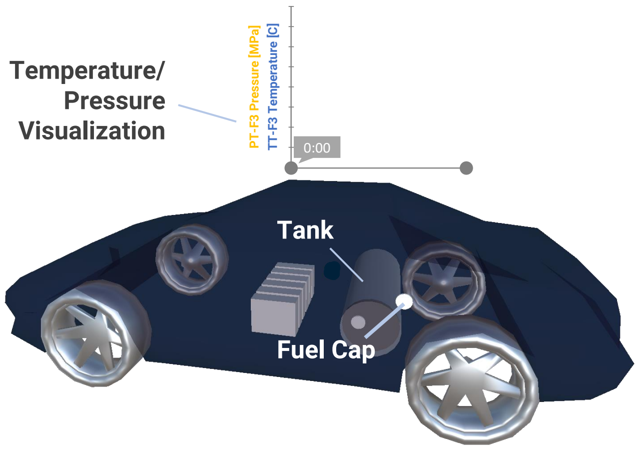

Figure 3: Diagram of the beginning of the fill-up simulation. When the user initiates the simulated fill by touching a physical nozzle to the fill cap, the tank begins to fill as the Temperature/Pressure fill profile above the virtual car populates.

fills up at the same rate as the visualization populates.

After the tour recipient has initiated the simulated fill and sees the fill profile populating, they are prompted by the tour administer to look back at the slide visuals. The final slides provide context to the simulated fill, describing it as an average fill profile of temperature and pressure in the tank. Subsequent slides also explain how these profiles vary when changing condition such as ambient temperature, and humidity. After this explanation, the simulated fill is finished, or is close to completion, resulting in a full tank and populated graph (Fig. 5b,d).

4.2 Tour Administer

The first step in administering the tour is to register relevant positions of key components of the hydrogen fuel dispenser through black and white fiduciary markers. In our initial prototype, we register each marker one-by-one, though upon iteration, we reduced the setup time for the tour administer by using just one marker on the central monitor display. These markers enable situated labeling of components of interest and situated visualizations (*HF1*). The fiduciary marker also defines where the PowerPoint slides render, since it is a central point in the dispenser at eye level. In order to provide a stable, accurate position directly on the surface, we had to reconcile the Magic Leap's marker recognition, which struggles to infer depth, against the spatial mesh of the dispenser. HydrogenAR calculates the point in the spatial mesh closest to the inferred position of the fiduciary marker 10 times and locks the average position as the central location for the slides, registering the breakaway box positions as a constant (X, Y, Z) offset from this central position. We implemented a function that allows the tour administer to "pick up" and move the car to any desired location near the dispenser by pulling and holding the trigger on the back of the remote to move the car, and releasing the trigger to place it.

After this initial setup, the tour administer gives the headset to the tour recipient and stands off to the side with the remote in hand for tour control. To cycle through slides, the tour administer swipes the touchpad to the left (previous slide) and right (next slide). A successful swipe initiates a small vibration of the remote and updates the radial light around the touchpad. HydrogenAR assigns each slide has a unique radial light pattern, such that the tour administer can quickly reference a document that maps the Magic Leap radial light color and orientation to a slide number to know which slide the user is seeing, if needed (*RG2*). Swiping the controller up and down cycles between three display modes. These modes render dispenser

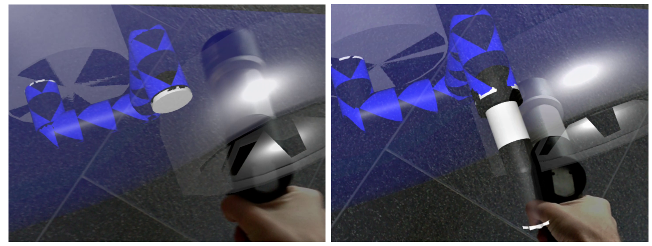

Figure 4: When the user touches the tip of the physical nozzle to the fill cap, a virtual nozzle renders and the simulated fill begins.

points of interest with either semantic labels, data visualizations, or no overlays. As with left/right swipes, a successful up/down swipe initiates a small vibration.

The tour administer also has controls associated with the car fill-up animation portion of the tour (*HF1*). The Hydrogen Fuel team mentioned wanting a mechanism to speed up the simulated fill, so when the tour recipient has initiated the tank fill-up, pressing and holding the back bumper speeds the tank fill and visualization population to 10x real-time speed. The middle button on the remote resets the tank and visualization, such that the tour administer can reset to the initial state for multiple users exchanging the headset.

4.3 Reuse and Extensibility

The source code for HydrogenAR is available for reuse[5]. The repository contains the fully constructed scene which can be directly built to a runnable Magic Leap application. The scene is meant to be deployed near the Hydrogen dispenser with a single printed fiduciary marker to register the center of the dispenser and render component labels relative to the center. HydrogenAR can be also be run from a separate location provided the central fiduciary marker is set on a wall or any other vertical surface. The repository also includes the prefabricated components used in HydrogenAR for easy reuse in future AR presentation systems: surface-stabilized image markers for label placement, labels Offset from the user's grip, display and control of slide visuals, and the car simulation with the line graph populating above it. Our hope is that future presentation designers can either use HydrogenAR as a base or reuse our prefabricated components for their own systems.

5 Evaluation

To validate HydrogenAR, we ran a within-subjects test of HydrogenAR and a PowerPoint presentation on a laptop. We tested with 11 end users (4M, 7F), where 5 saw the PowerPoint tour first, and 6 saw HydrogenAR first. We measured overall time to completion for the two styles of tours with HydrogenAR taking longer ($\mu = 7min, 12sec$, $\sigma = 46sec$) than the PowerPoint tour ($\mu = 5min, 15sec$, $\sigma = 52sec$). We recruited participants from NREL, but from different departments and in different roles (project management, data/computer science, physicists and UX design). The participants were not stakeholders on the hydrogen dispenser reliability team. We explained the purpose of the 30-minute study, and participants gave verbal informed consent for voluntary participation. We presented each participant with either HydrogenAR or the PowerPoint tour followed by the other system, with questionnaires after each. After both conditions and questionnaires, participants were given a comparisons questionnaire. We include the questionnaires as supplemental material and discuss results in this section.

5.1 Tour Content

We obtained slides and narrative content from the Hydrogen Fuel team and served as tour administers for the study. We more fully

[5] `https://github.com/CU-VisuaLab/HydrogenAR`

(a) Tank at the start of the simulation. (b) Tank at the end of the simulation. (c) Fill profile at the start of the simulation. (d) Fill profile at the end of the simulation.

Figure 5: Simulated hydrogen fuel fill-up. As time elapses, simulated hydrogen flows into the tank (a,b) and the Temperature-Pressure profile of an average fill populates in real-time (c,d).

described the system functionality in Section 4, but will summarize the tour content for the user study in this section. Both AR and PowerPoint tours begin with slides and a narrative that describes the problem space of hydrogen dispenser reliability—mainly that hydrogen fuel is increasing in usage, but the dispenser reliability is one of the limiting factors for broader adoption. After this motivation, we guided participants using HydrogenAR through identifying the different points of interest directly on the dispenser, with labels and visualizations overlaid on the breakaways and nozzle tips. To further explain a typical fill profile, participants in HydrogenAR are guided to initiate the hydrogen fill by touching the tip of a physical nozzle to the virtual fill cap of the hydrogen tank. In both versions (on a specific slide for the PowerPoint condition or the visualization of temperature and pressure over the car in AR), we explain the fill profiles as temperature and pressure over the course of a fill. Then, we show an average fill profile compared to other simulated fills where different parameters have been adjusted on slides. Participants in AR are then guided to look back at the car to see the fill profile mostly or fully complete. This concluded the tour, and we directed the participants to the questionnaire.

5.2 Results

After seeing each of the presentation formats, we administered a Likert-scale questionnaire. We asked participants questions how well they thought each presentation tool explained dispenser reliability and hydrogen fueling. We also asked if it would be an effective tool in explaining issues to tour groups, if it was engaging, and if it was enjoyable. After seeing both presentations, we administered another set of Likert-scale questions to allow participants to directly compare the two presentation tools. The comparison questionnaire asked which tool was better suited to explain the fill-up process and dispenser reliability, which tool was more engaging and which tool they would prefer to see deployed for tours. All questionnaires also allotted space for open feedback about the suitability of the presentation tool(s) and issues they may have had.

HydrogenAR provided an engaging experience that helped participants better internalize the issues presented. Appreciation for the engaging components of HydrogenAR was best summarized by a participant who enjoyed the "dynamic visuals which activated as I, the user, did something, I am no longer be talked at, I am part of the process." *(P6)*. Likert scale questions tended to be most favorable toward HydrogenAR in terms of engagement and enjoyment—a sentiment that was echoed in free response answers reporting HydrogenAR as a "very engaging format and highly demonstrative use of technology" *(P4)*. Participants pointed out perceived benefits, including that "observing the real-time fill parameters while the car was fueling was more realistic than just viewing the graph at the end" *(P3)* and appreciated the "identification of parts and seeing data tied to them." *(P8)*.

We found that participants typically preferred HydrogenAR to the PowerPoint tour both when asked to rate the individual tools and when asked to directly compare them (Fig. 6). Though preference was largely in favor of HydrogenAR, we found that results were most strongly in favor of HydrogenAR for questions about engagement and enjoyment, and most neutral for questions about understanding dispenser reliability. This feedback suggests that calling out the particular points of interest for dispenser reliability may not have been enough, but perhaps using animations of component failures in addition to 2D graphs may be useful.

There was some disagreement as to whether AR provided the better overview while PowerPoint provided better detail or if the converse was true. One participant explained that "the Augmented Reality tour was more experiential learning... whereas the PowerPoint presentation was better for the overall presentation of the data." *(P11)*. On the other hand, another said, "AR is better for demonstrating the fill up process, details are better shown via the PowerPoint." *(P9)* There were some issues with the slide visuals in HydrogenAR, as a participant suggested that "having the PowerPoints not in AR is nice, because the text and font are clearer" *(P1)* and that "the AR system was interesting, but slides need to be a little less text heavy" *(P7)*. One participant recommended doing away with slide-based components altogether, recommending that "there should be more focus on user guided interaction and discovery of information instead of being led through the entire presentation in a similar fashion as the PowerPoint" *(P5)*. Most participants saw benefits and trade-offs to both platforms, and three participants even recommended some combination of the two for future systems.

6 Discussion

Aside from being a useful tool within the domain of hydrogen fueling, we can generalize our findings from HydrogenAR to generate new guidance on how to effectively design data-driven stories in AR. Our design process also allows us to consider implications of our design and user feedback for future iterations of HydrogenAR and AR data-driven storytelling in general.

6.1 Implications for AR Data-Driven Storytelling

The problems that the Hydrogen Fuel team had with giving tours and presentations aligned well with the benefits of using AR. Thought they had data from simulated hydrogen fills, those simulations were run in non-descript boxes outside, making it difficult for visitors to conceptually map those simulations to a real dispenser. On the other hand, the team had a real dispenser set up inside where many tour groups walk by, but the lack of any interactive components, data, or narrative that would give the equipment context, making it seem sterile and inaccessible to passers-by. This combination of a wealth of data with a lack of context provided an ideal opportunity for AR data-driven storytelling. Future AR data-driven storytelling applications should focus on bridging gaps between important data and physical context, delivering it in novel, engaging ways, such that it does not get lost in traditional decontextualized media.

Application designers need to consider the user experiences both for the end-user and for the tour administer driving the experience.

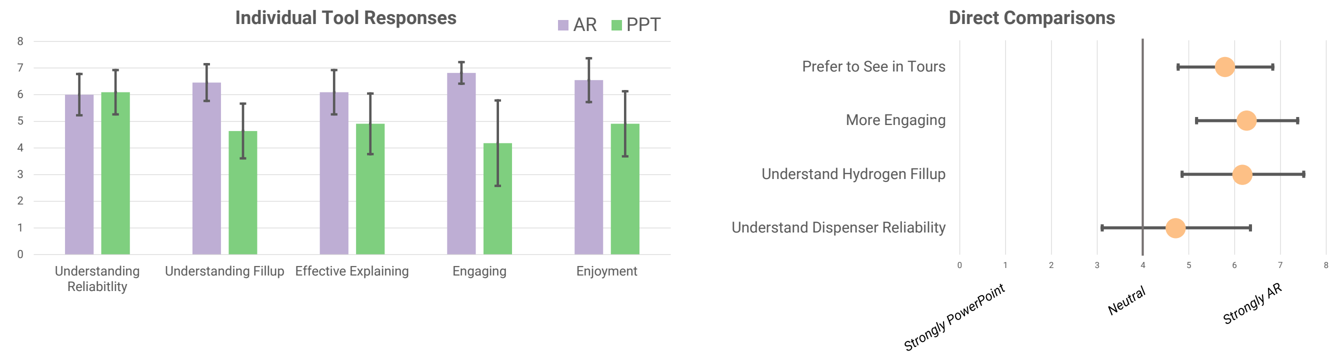

Figure 6: Comparisons of questionnaire results about individual tools (left) and direct comparisons of PowerPoint against AR for the final comparisons questionnaire. Error bars denote one standard deviation in either direction.

Feedback from the user evaluation indicated that the end-user experience is made considerably more powerful when the system reacts to their natural movements and actions (i.e., looking at the nozzle to load visualizations, using the physical nozzle to fill the virtual car). Tour administer experiences should focus on filling in the considerable gulf of execution [29] that arises when dealing with AR headsets—that the tour administer cannot directly see how their action affected the user's view. We utilize visual and haptic feedback on the Magic Leap One remote to inform the tour administer which slide they are on and when visualizations and labels are rendered over points of interest on the dispenser.

6.2 Future Work

Having evaluated HydrogenAR with end-users, we would like to continue collaboration with the Hydrogen Fuel team to work toward full integration into their existing tours. We specifically designed HydrogenAR with the intent that it be adoptable, so the next steps will include training the team to be able to guide users through the tour using the Magic Leap and the controller. Our study was able to evaluate the usability of HydrogenAR with tour groups, but continued feedback from a longitudinal deployment with the Hydrogen Fuel team would provide insight into how well AR integrates with tour groups and passers-by. With our preliminary evaluation being on people from various departments within NREL, extending this evaluation to real tour groups that come by would provide greater insight into how AR can fit into a tour workflow. Continued evaluation should also consider learning outcomes and how prior experience with AR technology affects the user experience.

Participants particularly appreciated the interactive components, with some participants recommending more AR-friendly visuals rather than porting slides to AR. While this may be a more engaging use of immersive AR displays, a more conservative approach to the integration of interactivity, tour administer controls, and 3D animations should also increase the likelihood of adoption *(RG4)*. Participant feedback also illustrated potential benefits of a traditional slide-based model, including that the PowerPoint "was easier to follow and provided a format that was expected" *(P4)* and that "it was a familiar way to be presented with information." *(P5)*. However, future AR presentations should explore formats that are more tailored specifically to the display type, as some participant feedback recommended doing away with slides in AR altogether We expect that the streamlined, straightforward nature of the PowerPoint narrative would be effective for the initial motivation of hydrogen fuel as a domain, and then the interactive components should only serve to build on that base knowledge, but this will be more effectively tested through extended use with tour groups.

Another point of consideration will be how a group of multiple users is able to engage with HydrogenAR. The ideal solution would be to integrate multiple headsets in a shared view—a feature that is currently available on the Magic Leap One. However, this solution would require enough headsets for each user, which is expensive and could become logistically cumbersome for tour groups of more than a few participants. An alternative is to use a built-in display such as the display in the hydrogen dispenser as a screen share, allowing all passers-by to see the first-person perspective of the headset wearer. Current methods for capturing first-person perspectives in AR typically overlay the virtual content on top of the camera feed giving an inaccurate depiction of the field of view and 3D nature of the AR scene. This approach also introduces issues of lag and reduced frame rate for the person wearing the headset. However, this shared view would help provide insight into the headset-wearer's experience and could make the experience more multi-user friendly.

HydrogenAR was designed and implemented specifically for the Magic Leap One, though as headsets continue to be released and improve on existing technology, the lessons learned from developing HydrogenAR can inform design of data-driven presentations in AR. Headsets should use integrated input/output devices to mediate the tour guide-tour recipient relationship—a solution that we implemented through the Magic Leap's remote. An important principle of hydrogen dispenser reliability that makes it an interesting use case is the ability to situate data from simulations directly onto physical infrastructure where relevant through graphs and interactive simulation. Future data-driven AR presentations should consider scenarios where we need to provide context to data as opportunities for AR displays to help the presentation flow. With thoughtful consideration of domains that could effectively utilize contextualized data visualizations, future AR presentation systems can improve tour experiences, rather than adding a gimmick that hinders presenters.

7 Conclusion

With HydrogenAR, we present a novel use of augmented reality for data-driven presentations, integrating data and virtual augmentations with physical infrastructure to provide an engaging experience that gives context to issues relevant to hydrogen fueling. We worked with the Hydrogen Fuel team to understand their needs and establish design requirements for AR data-driven storytelling for hydrogen fueling. In a qualitative user test, participants identified key tradeoffs between the HydrogenAR and traditional presentation media. With this work, we hope to integrate a working system into existing tours and inform the design and implementation of future AR data-driven presentation systems. We also provide a roadmap with preliminary steps to unlock immersive AR as display media for delivering presentations that integrate physical infrastructure with virtual visualizations and simulations.

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