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INTRODUCTION

There is a large body of research documenting the potential applications for augmented reality (AR) across various domains ranging from business and manufacturing to history and education (Arth et al., 2015; Dey, Billinghurst, Lindeman, & Swan, 2018). Such technology fosters informal learning (i.e., learning outside traditional settings) (Chiang, Yang, & Hwang, 2014), authenticity in education (i.e., making knowledge concrete and applicable), and enhanced learning achievement (Akçayır, & Akçayır, 2017; Bacca et al. 2014; Persefoni, & Tsinakos, 2015). Tourism and cultural heritage have also been addressed, with several experiences designed to support place restoration and involve visitors with additional content and insights about monuments, historical places, and beyond (Huang, Chen, & Chou, 2016; Kysela & Štorková, 2015). For instance, *Paradise Wildlife Park AR*, *Smithsonian National Museum of Natural History* app, *Conserv-AR* (Phipps, Alvarez, de Freitas, Wong, Baker, & Pettit, 2016), *Eco-mobile*, and *Discovery Agents* are programs that utilize augmented content to enrich learning.

AR is arguably successful because it harnesses embodied cognition (Gallagher, & Lindgren, 2015; Shayan et al., 2015), or the idea that learners acquire information with multiple senses to enrich a targeted environment. AR technology helps users visualize phenomena that are difficult to perceive (e.g., seeing layers of rock beneath a mountain surface); in doing so, it provides an embodied experience that enhances understanding, reflection, and memory. This potential can benefit learning experiences that are situated and go beyond formal and traditional boundaries, allowing any type of learner to access content that is tied to and mutually enriched by the surrounding space. Nevertheless, AR creative tools are still out of reach for the majority of content creators and educators.

In order to address this gap, this article introduces an augmented reality experience editor, exploring its core traits but also challenges. It includes an example AR path based around the events of May 4th, 1970, at Kent State University, also known as the Kent State Shootings. This specific focus is motivated by the fact that the landscape surrounding those events has dramatically changed in the last fifty years, making difficult to visualize them in their own context and locations. As such, AR shows promise in addressing such a pivotal event in recent U.S. history due to its emphasis on augmenting space, tying past and present. Moreover, preliminary results from two formal user/content creator evaluations are presented along with implications and future developments in terms of production and research.

BACKGROUND

Augmented Reality (AR) has been increasingly associated with place restoration and education due to its technical possibilities (Badouch at al., 2018). AR refers to the application of digital elements to real settings through the mediation of technology, from headset mounted displays (e.g., *HoloLens*, *Magic Leap*, etc.) to smartphones and supporting applications (e.g., *Pokémon Go*, *Ingress*, etc.) (Freina & Ott, 2015). The rise of mobile AR has made this technology more popular than ever and, as such, has fostered attention toward how fields like education and humanities can benefit from its features (Author 1 & Author 2, 2018). More specifically, AR has been used as a tool for making individuals active elements in their own physical context, addressing their needs and providing new stimuli for enriching reflection and community building. For instance, Garcia- Crespo et al. (2016) developed and tested an augmented reality system for improving tourism via games and quizzes activated in specific locations of historical interests. Pokrić and colleagues (2015) built an augmented reality driven game for teaching about environmental health and causes. Their system relied on air quality and other atmosphere factors as triggering parameters for delivering situational probes about pollution and nature. Harley et al. (2016) tested two AR mobile applications in Montreal historical sites and museums, finding that place identification and experiential engagement felt while using this technology were relevant and effective in teaching about cultural heritage.

There are four aspects of AR that are relevant to this article. First, one of the more novel uses capitalizes on place restoration, which provides a visual in which elements from the real world are integrated with digital ones (Freina, & Ott, 2015). Persefoni and Tsinakos (2015) observe that this utilization of AR "enables users to see and experience the real world mixed with various virtual objects, without losing the sense of reality" (p. 45). In particular, architecture, history, and design have all benefitted from the ability to show buildings or places that no longer exist or structures that could be put in place (Chi, Kang, & Wang, 2013). Second, despite the fact that AR can be realized through HMD holograms (e.g., Microsoft Hololens) and installations in-situ like *Meteor* (Gallagher, & Lindgren, 2015), mobile experiences via smartphone are the most popular application of this technology due to their affordability and accessibility (Arth et al., 2015). The increasing capability of mobile devices and geolocation features are supporting such a trend. The success of AR-based games like *Pokémon Go* and *Harry Potter Wizards Unite* has elicited a widespread interest all around the world (Pyae, Luimula, & Smed, 2016).

Third, AR shows promise in improving knowledge and informal learning among the public at large. Boboc et al. (2019) used AR for promoting Ovid's poems along with historical information in three locations: Sulmona, Rome, and Constanta. Their application was able to foster comprehensibility, manipulability, enjoyment, and usefulness among the public at large, highlighting how this technology can involve a variety of different users. Siriaraya et al. (2019) developed a geolocated storytelling experience by combining *Open Street Map*, *Google Street View*, and *Project Gutenberg*; poems and stories were provided to users according to their locations in Kyoto and San Francisco. These projects are aligned with the increasing use of augmented reality in literacy and the humanities. Moreover, Adapa et al. (2020) claimed that AR can also support and improve health literacy, allowing users to access information and also learn about their own wellbeing and emotions in a more effective and contextualized way. Klopfer & Squire (2008) developed a series of successful educational AR experiences about the environment, showing the potential of this innovation for addressing related topics like pollution.

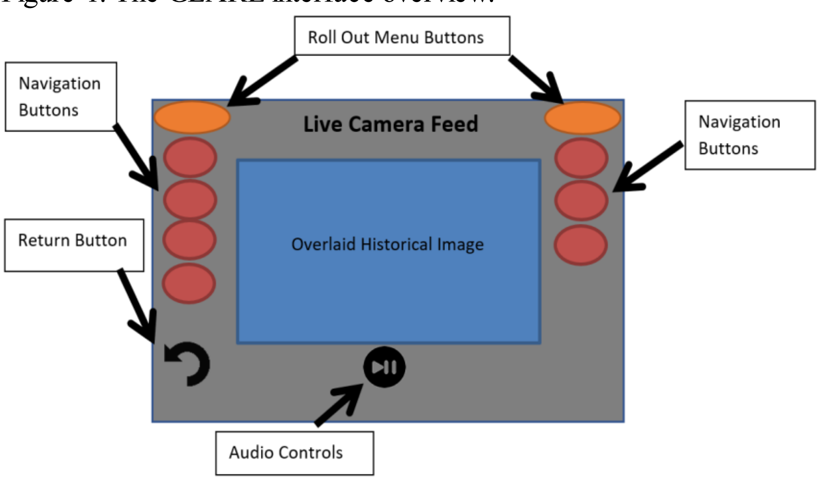
Fourth, even with the success of the technology, AR creation tools are still out of reach financially and skill-wise for the majority of educators and developers. In short, this innovation has shown promise for many areas and continues to find adoption, in part, because of the ubiquity of mobile devices; however, development of AR materials requires technical and design expertise that limits continued implementation (Gandolfi, Ferdig, & Immel, 2018). This is a relevant barrier for promoting and improving the use of AR in education. As Dunleavy and Dede (2014) claimed in their literature review about this topic, AR for learning is a complicated process that requires instructors and educators to experiment and explore different approaches and solutions on an ongoing basis.

In order to address this need, an AR framework called the *GeoLocated Augmented Reality Editor* (GLARE) was developed. For improving accessibility and customization, the design requirements included: 1) an open source code base; 2) a compatible website-based experience; and, 3) the creation of a framework that could be easily extended and reused to tell additional stories. To accomplish this, the project capitalized on *Github* (https://github.com/) for code hosting, *HTML5* (https://dev.w3.org/html5/html-author) for simple access to acquire geolocation, live video, device orientation (https://www.w3.org/TR/orientation-event) and device motion events, *JavaScript* (Flanagan, 2011) and *ThreeJS* (https://threejs.org/) to provide an interface to *WebGL* (https://www.khronos.org/webgl/) 3d rendering and image overlay on live video. The system was then tested on a project related to the events of May 4th, 1970, at Kent State University. The May 4th project was a significant case study because of the need to show geolocated content about specific events in-situ particularly tied to buildings or places that either no longer existed or had been changed significantly in the last 50 years. The emphasis on cultural heritage was motivated by the fact that this type of media experience can play a crucial role in promoting humanities topics, such as that crucial day in American history. As argued by Saggio and Borra, (2011), "the virtual reconstruction/restoration can be even improved taking advantages of the AR, which furnish lots of added in-formative parameters, which can be even fundamental under specific circumstances" (p. 59).

GLARE

The interactive and augmented experience was designed from the outset with cross-platform compatibility in mind. Running within the browser and built using newer web specifications, the software was designed to be vendor agnostic. Participants connect to a website housed on a web server and are greeted with a prompt to begin the tour, an associated audio file describing the experience to orient the user, and a background image selected by the tour designer. Once a tour is initiated, the users camera is activated and, depending on whether the user is at the starting geolocation, the website either: 1) displays the map with the users position shown as a red teardrop; or, 2) in the event that the participant is located within 2 meters of the hotspot, the AR interface is loaded for the hotspot location. Each hotspot embeds an image that overlays camera visuals through the phone screen and initiates the hotspot specific environmental audio sample to play automatically. Clicking, or tapping, the first navigation button initiates additional audio. Users may return to the previous page, access the map, or control audio via the on-screen icons (see Figure 1).

Figure 1. The GLARE interface overview.



The specifications of the software center around a website designed to run across platforms within the browser. All tools utilized in the development of the project are fully developed open-source libraries and freely available for use. The website uses *HTML5* web features in order to provide a seamless augmented reality experience on any device without the need for download of an app from an external store. *HTML5* has simple access to acquire geolocation, device orientation and device motion events that are used in the current project. The website renders historical images navigational components using *JavaScript* programming of the *ThreeJS* library for drawing interactive 3D content utilizing *WebGL*. *Google Maps* (https://www.google.com/maps) and the geolocation API (https://www.w3.org/TR/geolocation-API) are used to acquire the users' position and render the map. Geolocation is used to identify whether a participant is located within a hotspot to initiate the content delivery as well as provide location data on the map. Device motion and device orientation events are utilized by to identify the direction the cellphone is facing and rotated to adjust the position of the rendered content. The extensive tutorials and simple programming interfaces are well suited to complete the necessary tasks efficiently and cross-platform. Figure 2 represents the general GLARE architecture; Figure 3 shows the user interface flow; and Figure 4 presents the file architecture of the application (the markers.json file contains the tour configuration).

Figure 2. GLARE general architecture.

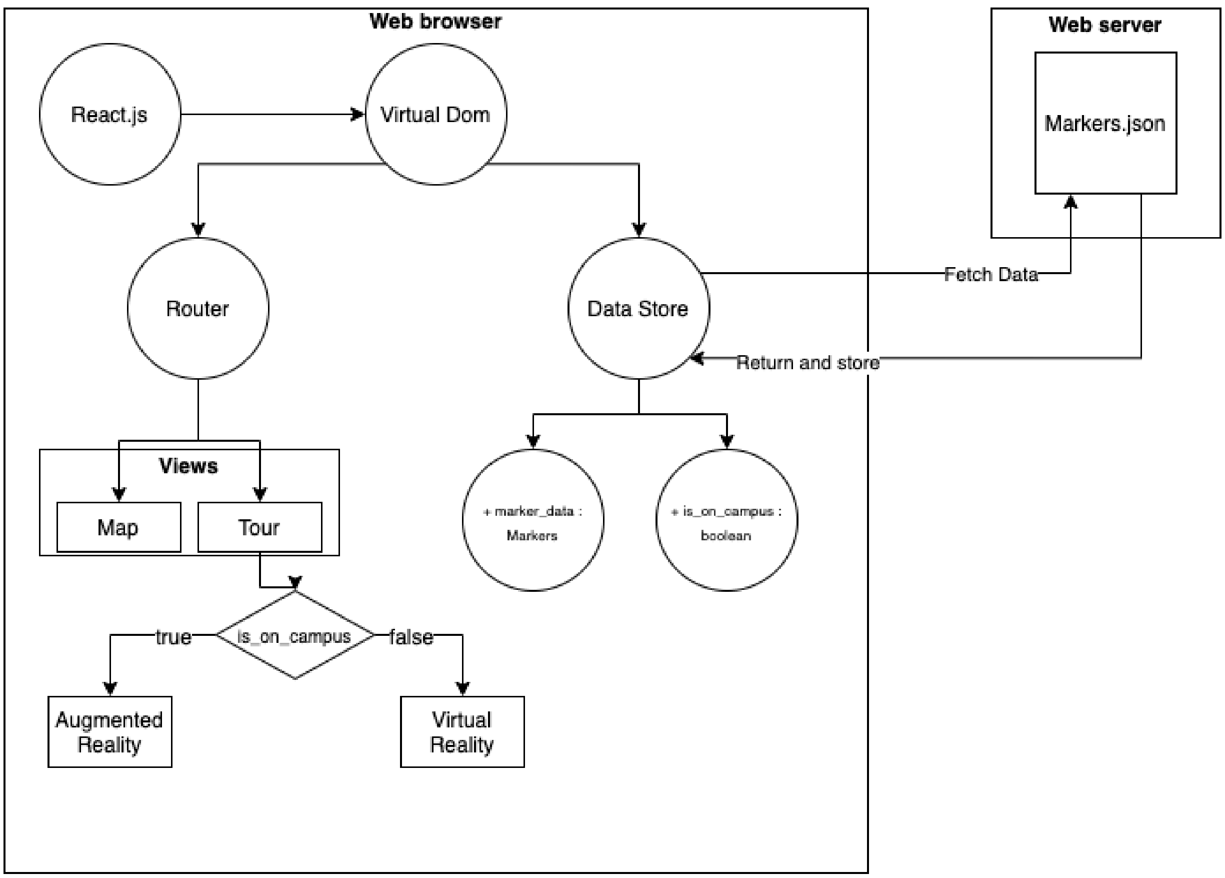


Figure 3. User interface flow of the design of AR development tool.

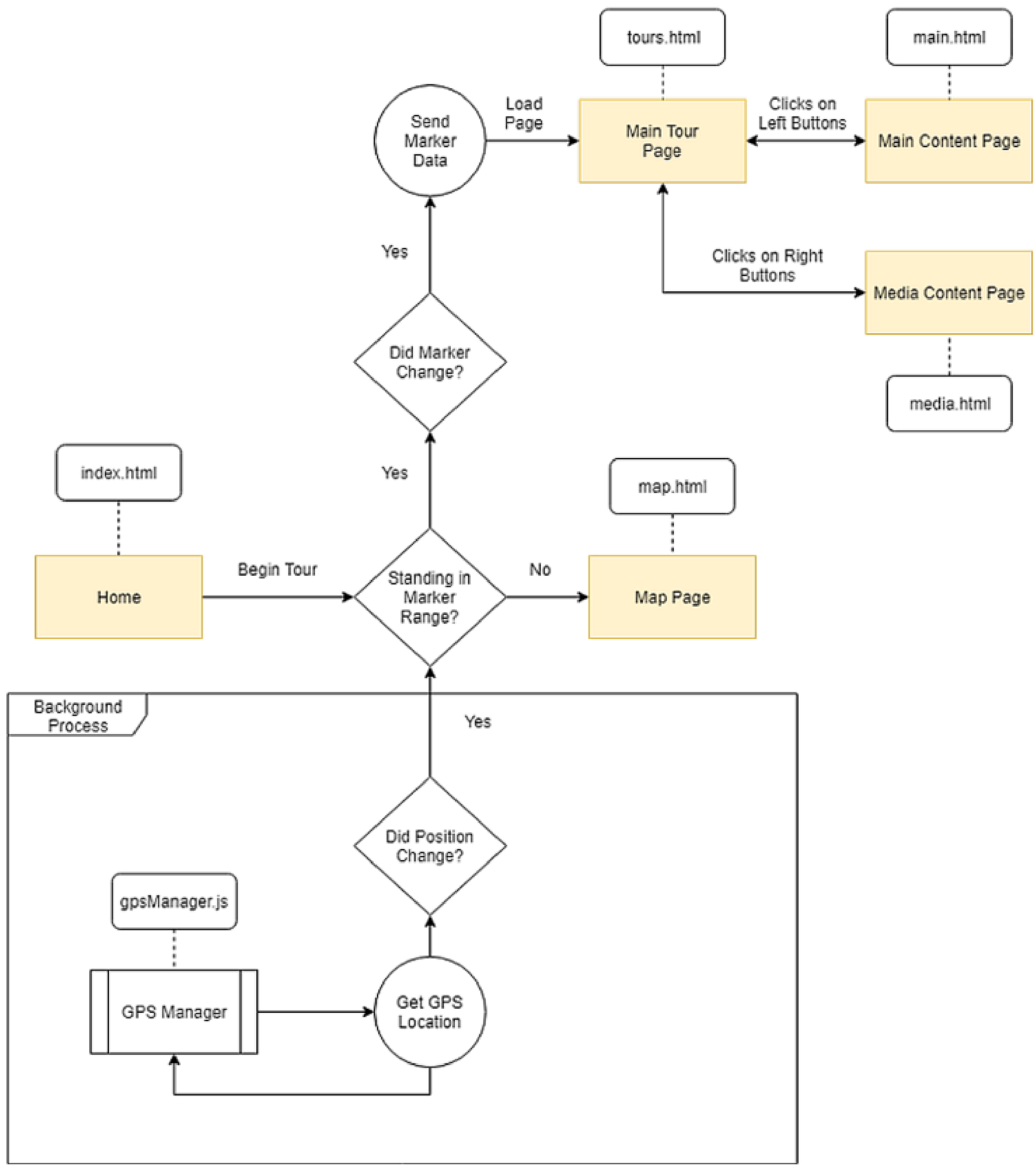
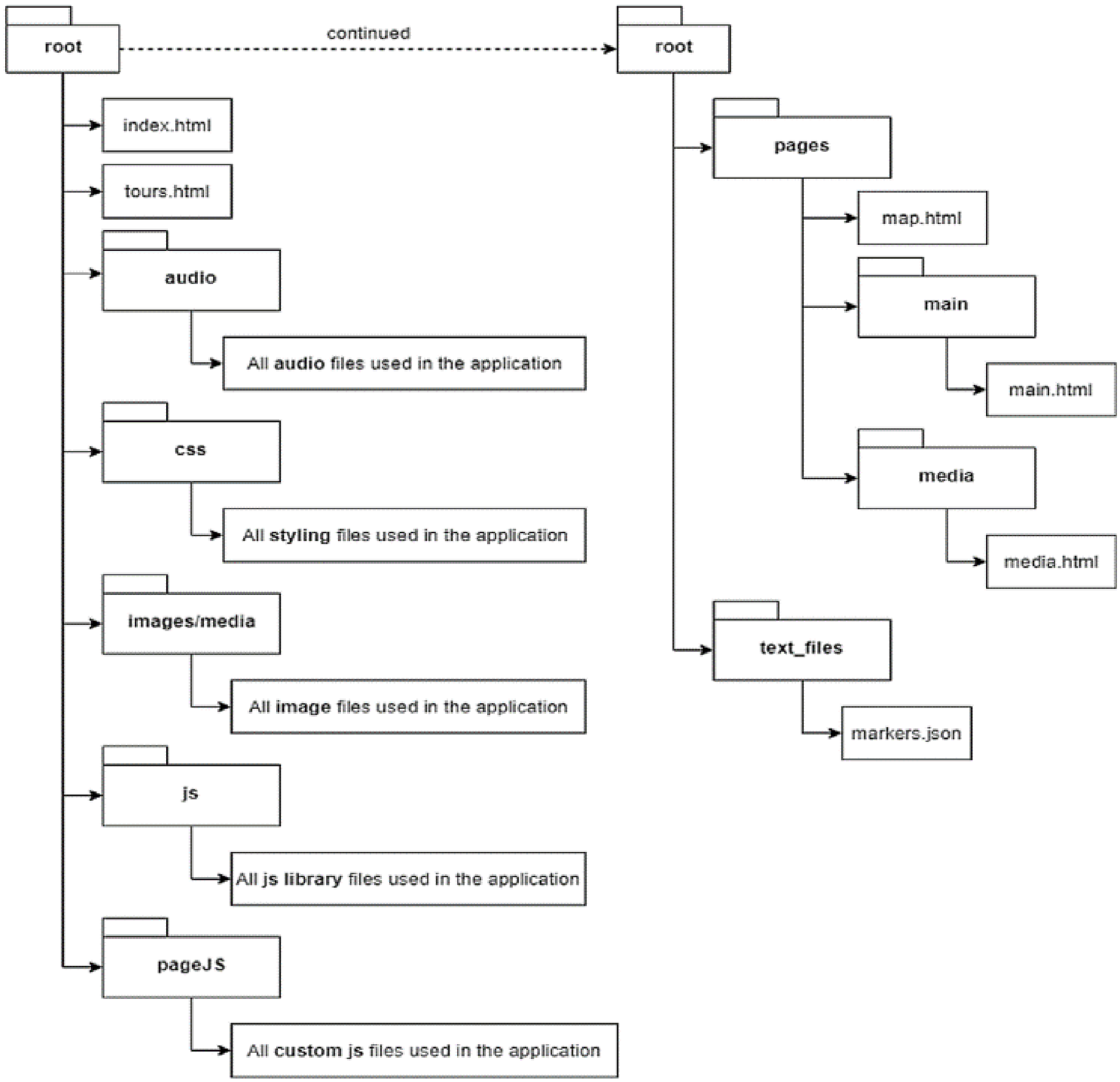


Figure 4. File architecture of the AR Framework.



GLARE is designed for configurability and relies on defined materials within the *markers.json* file content. From within the AR experience, hotspots are dynamically loaded from the preconfigured JSON file containing a list of all content in the tour (see Figure 5). Each hotspot section has a GPS coordinate and associated media (overlay image, images, audio and links) organized by section within the interface. This enables simple adding and changing of links by modification of the user selected list.

Figure 5. Sample JSON file describing geolocated content related to the May 4 events.


```
"position": 1,
"latitude": 41.150186857592914,
"longitude": -81.34437203407289,
"name": "Victory Bell",
"main_pages": [{
        "title": "Context (May 1st)",
        "description": "On May 1, 1970 a group of approximately 500 students gathered at the Victory Bell to protes
        "background_image": "../../images/VictoryBell-1.jpg",
        "descriptive_audio": "../../audio/a-context.mp3",
        "oral_history_audio": "../../audio/a-context.mp3"
}, {
        "title": "5/4/1970",
        "description": "After a weekend of turmoil off campus and on, an estimated 2000 people, gathered that Monda
        "background_image": "../../images/VictoryBell-2.jpg",
        "descriptive_audio": "../../audio/a-5-4-1970.mp3",
        "oral_history_audio": "../../audio/a-5-4-1970.mp3"
}, {
        "title": "Commemoration",
        "description": "Since 1971, friends, family, and students gather in silence at the Victory Bell at 11:00 pm
        "background_image": "../../images/VictoryBell-2.jpg",
        "descriptive_audio": "../../audio/a-commemoration.mp3",
        "oral_history_audio": "../../audio/a-commemoration.mp3"
}, {
        "title": "Voices for Change",
        "description": "Why did students protest in 1970?  Should students protest today? What gives Americans the
        "background_image": "../../images/VictoryBell-2.jpg",
        "descriptive_audio": "../../audio/a-voicesforchange.mp3",
        "oral_history_audio": "../../audio/a-voicesforchange.mp3"
```


The hotspots are associated with an audio sample, an overlaid historical image and a collection of identified links residing in the definition file. Explicitly coding the list of hotspot-related links permits complete control over the AR experience to allow users to select impactful media to recreate the past from within a framed humanitarian viewpoint. Specific links associated with each hotspot and related themes can be developed throughout to portray the events while immersing the user in the past through the lens of AR. The AR framework is controlled by editing a simple text file (see Figure 5) to create paths with any number hotspots with custom content. Future iterations will include a graphical and drag and drop interface so new tours can be created visually. GLARE is also modular, whereby the interpreter will parse the content of the file and only populate those objects/media that exist within the configuration. This adds a degree of flexibility to the platform permitting any number of menus, library links and other content loaded in a modular fashion. This method also allows for the simple addition of new modules in the future (i.e., haptic interface/ point cloud rendering) that are easily incorporated into the platform.

Novelty

While various tools have accomplished some of the aforementioned features (e.g., *artoolkitX*, *AR.js*, *AFrame*, etc.) GLARE combines them into a single framework with four advantages. First, the project is open source and designed to provide a platform for further enhancement that is not a programming library (e.g., like AR.js). Rather, it is a specific application for rapid prototyping and evaluation of AR experiences. Second, the project does not require coding skills to create dynamic multi-modal experiences. It is specifically geared towards the end user (not program developer) and designed up to be a framework on which users content resides. Third, to our knowledge, this is the first open source, multi-modal AR system that can be set up by the simple editing on a webpage and works cross-platform on the web. Further our application works out of the box and has GPS/map functionality embedded within the software. Fourth, we provide a more efficient way to develop new position-based experiences without the requirement to compile code (or upload to application stores).

Usage Scenario

As a working example, an AR tour was created using the GLARE framework. It was based around the events of May 4th, 1970, at Kent State University (https://may4thxr.kent.edu). The experience includes both physical and digital components; it invites users to view perspectives of the Kent State shootings through historical imagery, audio, and related other media that highlight humanitarian struggles. When the user enters the website, an audio file launches that describes how the experience works (see Figure 6). Upon clicking the "Begin Tour" button the user enters either the map view or hotspot view depending on geographic location.

Figure 6. The May 4th AR tour landing page.

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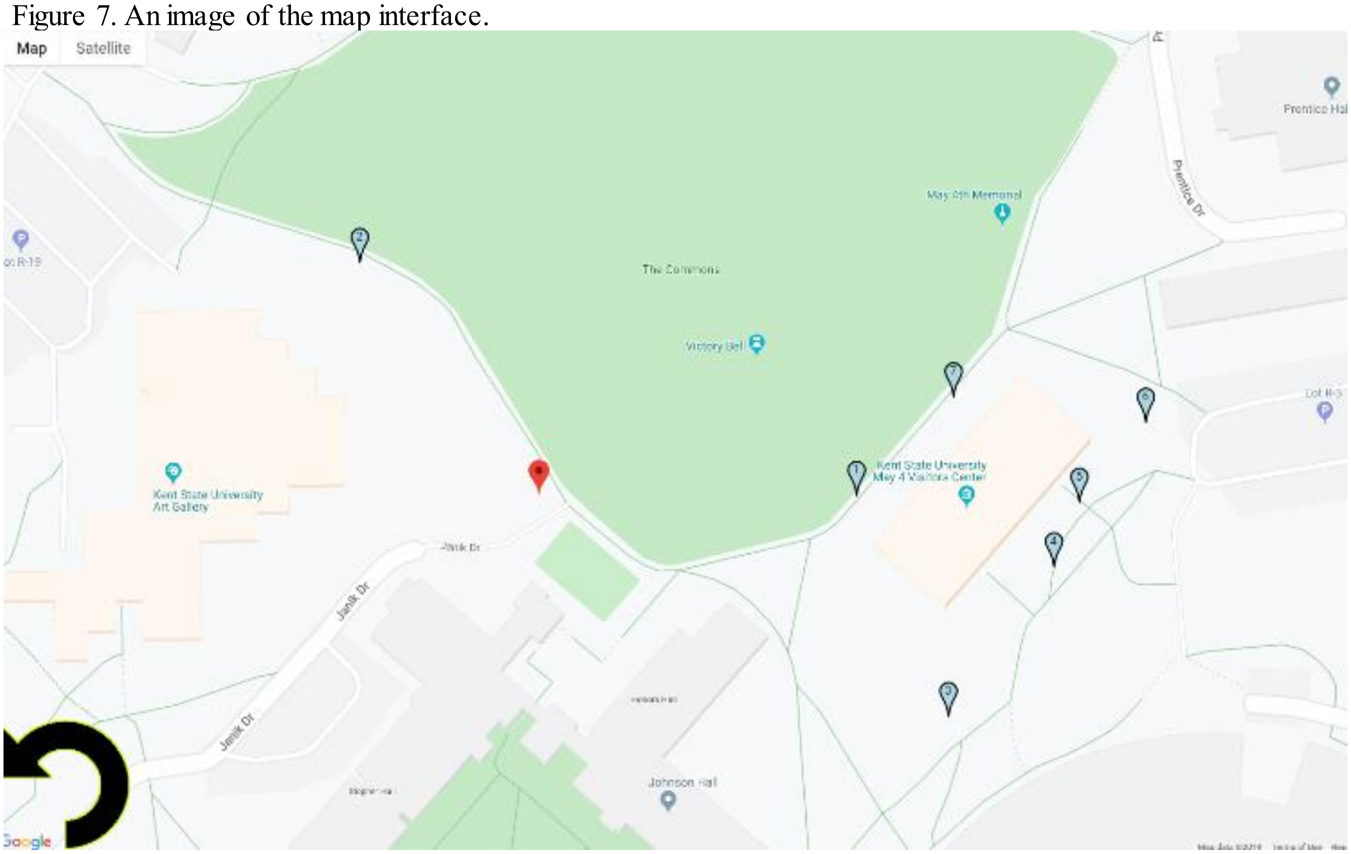
As the tour is initiated, participants follow a trail through the Kent State Campus that chronicles the events of May 4th. Seven AR hotspots along the path transport the audience to that fateful day via the use of images overlaid on present day imagery as well as informative and reflective audio. Users view the events from the same physical space and time through pictorial and aural historic place restoration. Each hotspot focuses on important aspects of the events and underpin humanities themes. The background image, text, and triggered audio file are determined by the main configuration file. When the user clicks the begin tour button they are asked if they accept that the application will track user location and allow hardware camera access. Once accepted the user is placed within the map interface where light blue teardrops indicate hotspot location, and a moving red teardrop displays the users' current position. Device GPS position is tracked, and the red teardrop position is updated. The user is prompted to walk to the first hotspot and follow the path in numerical order. When the user is within a specified hotspot location the interface is automatically generated and displayed based on the media files associated with the configuration document. The radius of each hotspot can be configured to adjust the geographic threshold that loads the associated content within the screen frame (see Figure 7).

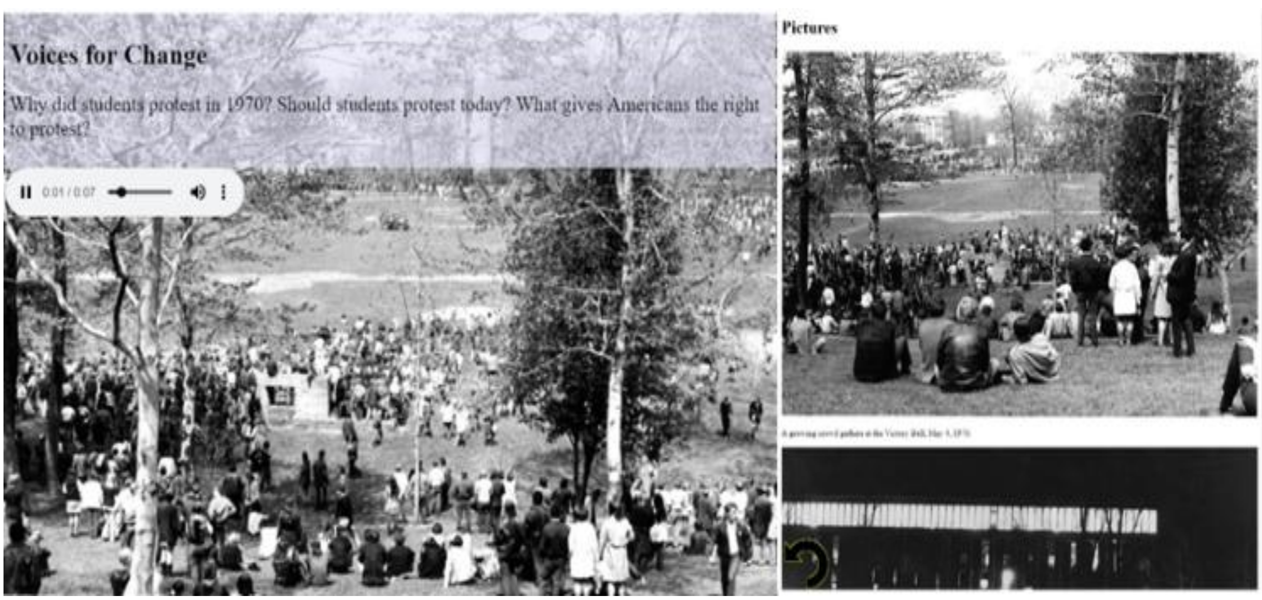
Figure 7. An image of the map interface.



Each hotspot includes live video from the device camera with an overlaid historical image. The image is normalized to the camera position when the user clicks "Show Me" and orientation based on the position of the users' device. An audible description indicates the relevance of the geographic position. The left menu contained four buttons: "Context", "May 4th", "Commemoration," and "Voices for Change". Menus were configured in the setup file and linked to a textual description that fades out after an audio clip ends to reveal an historically relevant image pertaining to the selected button. On the right side of the interface, three additional content buttons were created in the original configuration file; 'Pictures", "Audio" and "Links". The first links to an image gallery, the second to several audio histories, and the third to links pertinent to the experience. Figure 8 represents the first hotspot titled, "The Victory Bell" on the seven-hotspot walking tour exemplifying the user interface. Figure 9 displays a) on the left an example of the submenu content for the created tour, with an image displayed with text that gradually fades out and an audio clip played to the user and b) on the right the "Gallery" media section where images with captions can be scrolled and viewed by the user. The additional media tabs include links to external content; all media and links can be customized in the configuration file.

Figure 8. An example hotspot from the AR tour.

Figure 9. Example menu tabs and additional media links.



Evaluation

The evaluation phase of our platform relied on two phases – a) the GLARE AR editor evaluation and b) the May 4th Prototype evaluation. Both the studies were approved and monitored by the authors' university IRB committee.

Sample and recruitment

The GLARE AR editor was tested with 6 content creators (4 females, 2 males, age mean = 36.1) with no previous experiences with AR development and an interest in poetry and healthcare (due to their profession). The May 4th prototype was tested with 14 participants (5 males, 9 females, mean age=21.4) to evaluate the usability of the framework. For both the studies, the participants were recruited using purposeful sampling (Wiersma & Jurs, 2009) though the authors' university listserv.

Procedure and methods

The content creators were asked to create an augmented reality poem to locate in an urban area following instructions (i.e., a tutorial and a selection of materials to include). They were then prompted to create a second hotspot from scratch about health information related to the COVID-19 pandemic. After their experience, the content creators completed a *System Usability Scale* (SUS) (Brooke, 2013) about GLARE and were invited to share their viewpoint about its strengths, weaknesses, and possible improvements with semi-structured interviews delivered via email. SUS is a well-established and validated instrument for evaluating technology accessibility; it is composed of 10 items with a 5-point Likert Scale (from strongly agree to strongly disagree). The scoring involves conversion and multiplication processes, with a final range of 0-100; a SUS score higher than 68 would be considered above average (https://www.usability.gov/how-to-and-tools/methods/system-usability-scale.html). It has been widely adopted in evaluating new technologies and especially immersive reality (Dayarathna et al., 2020; Ma et al., 2019;). Our goals were to test GLARE accessibility and flexibility in covering different creative needs and objectives.

The May 4 study participants walked the physical path and were split into two focus groups. They were able to autonomously navigate the experience following the physical path using the digital cues while engaging in the story by our selected media content. After the tour and prior to the group interviews, they completed the *HARUS* scale (Santos, Taketomi, Sandor, Polvi, Yamamoto, & Kato, 2014), which is designed to evaluate AR software usability. HARUS is composed of 16 items with a 7-point Likert scale (from strongly disagree to strongly agree). The scoring system is similar to the SUS with a range of scores from 0 to 10. The HARUS scale evaluates manipulability (the user-friendliness of an AR application) and comprehensibility (the readability of the information provided by the AR system). Focus group questions asked about general usability, engagement with the mobile experience, and involvement with the topic addressed by the prototype. The sessions were recorded, transcribed, and analyzed by two researchers looking at main limitations, strengths, and areas of improvement regarding the AR experience developed.

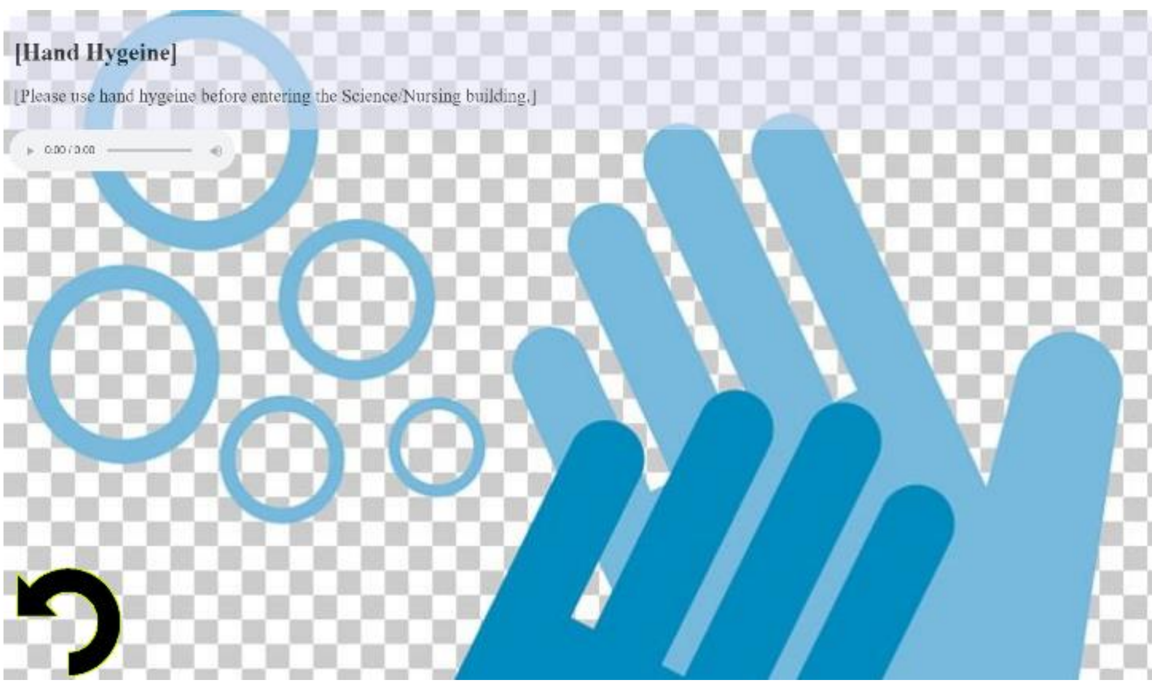
Results

Content creators

Figures 10 and 11 show examples of testers' creations, with augmented poems associated in pertinent locations (e.g., a poem about a river near a real one) and augmented health information (e.g., cleaning hands) provided in appropriate buildings (e.g., a nursing institution). Creating the poetry-based hotspot took around 90 minutes, while the second AR landmark about COVID-19 took approximately 60 minutes. This change indicated an increased familiarity with the editor after the first attempt. SUS results pointed to a good usability (m=76, sd=7.1), while participants' feedback highlighted two GLARE strengths. First, it had versatility in including any type of content and potential theme; and, second, the immediacy of the passage from creation to use and testing without going through additional passages. Two weaknesses emerged. First, GLARE was only partially accessible for creators who were not proficient in programming and who may have issues while filling the JSON file. Second, the interface needed be made customizable by creators. Users suggested that creators develop extended tutorials and to add a graphic user interface (GUI) for making GLARE even more accessible; they also wanted additional customization features.

Figure 10. Example of a hotspot about poetry.

Figure 11. Example of a hotspot about hygiene.



May 4 prototype users

Results from the HARUS scale pointed to a manipulability (mean=37.2, sd=3.2) and comprehensibility (mean=40.3, sd=4.1). Said differently, the May 4th experience was usable and could be considered an informational AR experience. Five key strengths were noted by the users during the two group interviews. First, the role of space for addressing the content (in essence, the use of geolocated AR) seemed to make history come alive in novel ways while re-framing familiar settings (all the subjects were Kent State students with some knowledge of the May 4 events). Second, the users pointed to the autonomy that allowed the user to take time in exploring the path and decide the hotspot order. Third, the elegance of the content (from information to prompts for reflection) was concise enough to maintain the focus on the real environment. This included positive appreciation for the layout that was described as intuitive to use. Fourth, the online infrastructure made the prototype easy to access and share with mobile devices (e.g., no download required). Finally, participants valued the tour as an informal education agent that taught them less known facts related to the May 4 shootings (e.g., the controversy about building the Gym annex after the shootings or knowing that several ROTC buildings were burnt down across the country).

Users also pointed out three limitations during their experience with the prototype; it can be argued that these limitations refer to experiences with AR at large beyond the events of May 4th. First, more personalization features were desired to support content visualization (e.g., text font). This addition implies the ability to provide configuration options without modifying the experience planned by the creators. Second, users wanted full device compatibility and accuracy to automate the orientation of overlaid imagery to make the experience more immediate and immersive. Third, testers observed that final users should be able to upload their own content related to the AR experience. Such options arguably need to be carefully considered for not altering the purpose of the designed tour. Table 1 summarizes the main strengths and weaknesses of the May 4 AR tour (offered by users) and GLARE (given by content creators).

Table 1. Main GLARE and May 4 tour strengths and limitations

Main strengths	**Main limitations**
GLARE	
versatility in terms of content and focus immediacy from creation to use and testing	Potential issues with JSON file management Inability to change the AR tour interface
May 4 tour	
Synergic role of space Autonomy given to users Well-balanced amount of content Online-based approach Educational component about May 4	Lack of personalization Average device compatibility Absence of user generated content

DISCUSSION

This article describes the creation of GLARE, an open source, easily configurable, and extendable framework with a simple interface for customization. GLARE allows interactive (in this case historical) images to be overlaid on live video at any global position and associates each position with multimodal media (images, audio and video). Importantly, engaged users can spend time locating relevant media content to populate the experience rather than coding and debugging the underlying structure of the website. Further, the system shows good compatibility across mobile devices because it exists simply as a hosted website. The mobile compatible website serves as a means to bypass mobile app stores and related downloads, which can serve as significant barrier to production, maintenance, updates, and adoption.

In creating and testing GLARE we faced multiple challenges and learnt several lessons. First, cross platform compatibility can be a continuing problem based on browser and operating system updates that can break the code (as happened twice during our development cycle). Second, debugging should be done on hardware devices (emulators sometimes do not accurately relate to hardware) where possible as well as in a cross-platform manner from the start of the development cycle. AR ap-plications are richer with high resolution media, but during tour creation significant considerations had to be taken to reduce media size to avoid caching wait times at the hotspot. Therefore, care should be taken to under-stand impact on the experience and trade-off download times with user experience. Third, internet connectivity can also be an issue and should be evaluated when de-signing the radius of AR hotspots, this can be due to patchy cellular coverage or non-existent WIFI. This issue can be partially mitigated by pre-caching the data and increasing the hotspot range, however, network access at hotspots should be evaluated during design. Fourth and relating to end-user data configuration and the json file structure, JSON was used due to its simplicity in integration with the underlying code and simple access to variables. However, as users edited these files it be-came apparent that a single aberrant character can break the configuration so could become problematic. As suggested by the testers, a GUI to configure the tour graphically is under development. However, an immediate remedy is to validate the contents of the json file in an online json validation tool (e.g., https://jsonlint.com/) to ensure file compliance and ultimately tour functionality.

The feasibility and utility of the framework for storytelling was tested in two different studies: one relying on a creative task for testing GLARE editing features and one in the form of an augmented reality tour based around the shootings that occurred at Kent State University on May 4th, 1970. Content creators were able to design and build their own AR experience in a short amount of time despite the absence of a GUI. They appreciated the flexibility of GLARE in terms of content to upload and its open-source approach; in addition, they highlighted the benefit of testing their product immediately after working and revising the JSON file. Their creations are just a first example of the potential of this editor, also considering that the content creators recruited had a limited amount of time for mastering GLARE and its features. Therefore, our planned goals were matched in terms of access and flexibility in dealing with different subjects. This outcome is well aligned with the need of more AR editing tools for educators and instructors (and beyond) (Gandolfi, Ferdig, Immel, 2018), supporting experimentation and exploration of new approaches and strategies addressing AR and learning goals (Dunleavy & Dede, 2014).

The ability of the framework to produce a seamless experience to convey historical content via augmenting the physical space was also demonstrated. Testers involved with the prototype evaluated the augmented experience, positively praising the importance of space as an effective bearer of immersion. This is an interesting result considering that, being Kent State University students, they were already exposed to the materials addressed. Such an outcome can be tied to the situated/informal learning (i.e., content delivered in non-traditional ways and within concrete contexts), which is an intuitive area of application for augmented reality interventions. Moreover, the freedom given to the user to explore the path and its contents were some of the users' favorite features. This data suggests that geolocated learning instances may benefit from autonomous and flexible navigations, avoiding overly guided experiences and supporting active learners. Theses analyses also show that the framework (when correctly configured) can not only be used as an informal educational tool/experience, but also as a method for historical preservation and storytelling (in our example chronicling the events at Kent State for the 50th anniversary). These findings echo the increasing use of mobile AR for humanities related causes, from cultural heritage to history and place restoration targeting the public at large (Garcia- Crespo et al., 2016; Pokrić and colleagues, 2015; Boboc et al., 2019; Siriaraya et al., 2019).

Implications for AR development

From the outset of the project, the trajectory was to deliver an experience to showcase a humanitarian event that was not overly technological to support end-users with varying degrees of device competency (e.g., a wide age range). One of the most important choices made was how to overlay the historical image on the camera feed with minimal user intervention at the hotspot location. Conceptually, three methods were addressed that could potentially be employed to accomplish this:

1. Printed AR markers and loading content based on camera recognition of the markers.
2. Physical markers within the existing landscape and comparing to acquired camera frames.
3. Using device orientation events to adjust the position of the overlaid image.

AR markers suffer from significant frame drops and speed reduction when using older devices with less computational power. This causes inaccurate overlay as well as a less than fluid experience (e.g., a jerky model position). In addition, the AR markers within the camera scene need to be relatively large, or risk acquiring high resolution camera images that further reduces frame rate. The second option of using image recognition of scene content suffers from similar issue with computational resources on older devices. A larger issue, for the application at hand, was the changing landscape at each hotspot due to seasonal weather. Leaves, rain, snow and other variables in weather patterns means that it is difficult to have a single view to recognize, reducing accuracy and reliability. This approach is arguably more successful when dealing with a well-controlled and non-varying (indoor) environment.

As such, the third approach of utilizing device orientation events was selected to provide image overlays. The method removes the necessity for frame-by-frame image recognition, increasing performance on older devices. However, it does limit the AR experience to a single positional viewpoint that must be taken into account when designing tours.

The implementation of GLARE necessitated its accessibility from many computational devices spanning ecosystems. Discussions of specific versions targeting the end devices was quickly muted due to the extra level of app stores and version control that would have slowed down development and updates. Advances within capabilities of websites to access hardware accelerated components of user devices coupled with mature libraries capable of harnessing these routines allowed a website distribution platform to be developed. Developed content can thus be accessed across devices from VR devices to laptops, tablets and cellular telephones at a single access point without the requirement for end-users to download an application from a third-party. Further enhancing compatibility across devices, the *ThreeJS WEBGL* programing interface provides access to many existing routines for data manipulation and spatial visualization, most importantly for acquiring sensor data from many devices. One of the challenges of AR experiences is controlling and maintaining a similar experience across devices and a major goal of the current project since empirical evaluation was planned. The approach here limits the complexity for the end-user, however, due to our development choices the platform has an interface to many additional features (within the API frameworks and beyond) via a modular design.

Reliability and consistency of acquired hardware sensor data is also critical to a fluid AR experience, and issues associated with must be addressed. The May 4th AR tour sees users walk a physical path containing hotspots, where position is updated real-time on a live map within the website interface using device GPS data. When the user is within a radius of 20 feet from the hotspot center the content activates and displays a virtual overlay, hiding the map. A radius of 20 feet was selected for the May 4th tour due to the distance between hotspots, to avoid overlapping hotspots and since it provided a level of reliability as tested across numerous devices even with slower update speeds and across the physical path that includes height variability. Essentially, users could be guaranteed to be within the target location boundaries with good reliability, essential for a location-based experience. Early evaluations tested the use of device motion and device orientation sensors to manipulate the view of the AR image at each hotspot. Both translational and rotational scene changes permit the user to effectively walk around the overlayed content and manipulate the viewpoint. The implementation necessitated creation of a new engine, the *SLAM* engine. Essentially this included creation of an ellipse the size of the earth (but not exactly for performance) and then plots markers on top of this eclipse. Unfortunately, GPS was too unpredictable across devices and even applying statistical filtering (e.g., the *Kalman* filter) did not prevent the user from jumping from place to place as they walked. Even with using some accelerometer data, things were a bit complicated, so it was never opted to be used. While technically this method provides a greater degree of flexibility, the implementation failed to produce satisfactory results (e.g., inaccurate overlay, jerky positioning, slower operation on older devices, etc.). Further, the images overlaid were of larger scenes and would require users to exit the hotspot to fully circle the image and provide little intrinsic value. However, device orientation events extracting data from gyroscopic sensors providing information about rotation of the device across the three planes provided a method to manipulate the viewpoint reliably. These data are relatively consistent within and across devices and using the programming interface to link the *WEBGL* camera to the output of the sensors provides a smooth experience.

The major drawback from this approach is that only a single viewpoint can be manipulated. This can be mitigated by intelligent tour design, and in the described May 4th tour two issues arose when designing the tour. Practically, the overlaid image is essentially a two-dimensional map that is applied to a portion of the inside surface of a transparent sphere. The spheres rotation across the three axes is adjusted by device orientation events and the image appropriately moved within the viewpoint. Due to the fixed viewpoint of the device, orientation approach issues regarding GPS sensor inaccuracy and differences in end-users must be accounted for. Variability in update speed and GPS accuracy across devices means the user may not be in the exact same physical position on each device, and as such the overlay will be different. Subject height also adds a further level of variability to the viewpoint and final AR experience. Each of these issues were minimized in the May 4th tour by carefully selecting hotspot locations that were a relatively far distance away from the target position, which was essentially dictated by the availability of historical imagery. For each selected image hotspots were located 50 to 100 yards away from the target view and as such the variability in user height (approximately 2 feet assuming users between 4 foot to 6 foot tall) adds negligible changes in a viewpoint over the 50-100 yards away (coupled with the fact that the landscape has changed, sometimes significantly). XY position of the user provides slightly more variability but still acceptable once the 20-foot hotspot radius was selected.

Another issue that must be mitigated is the original orientation of the overlay image in respect to the user position, the image must be rendered pointing toward to area or interest. Newer devices contain reliable compasses, and the position of the image can be simply adjusted based on the position of north indicated by the compass. Reliability on older devices is inaccurate and unreliable as such alternate methods must be used to fine tune the orientation. Our approach is two-fold to solve the problem, intelligent approximation, and manual fine tuning. Since tours follow a specific route and are a sequential experience, users generally follow a similar path to each hotspot. As a result, the position of users in the May 4th tour can be estimated to be along the path pointing toward the hotspots and when entering hotspots, the initial rotation of the overlay image is estimated to be based on this trajectory. To provide greater flexibility to users, deal with sensor errors and unpredictable behavior, a button has been added to the interface to align the overlay image with viewers direction. While these methods are utilized to adjust rotation of the viewpoint around the user, our studies suggest the rotation around the other two axes are predictable and stable across devices.

The limitations of using sensors on a wide range of devices to provide similar cross platform AR experiences is a great challenge, especially if user outcomes are being empirically evaluated. For the implementation of GLARE for the May 4th project the approach was to limit technological requirements for end-user devices for wide cross platform use and dissemination. The limitations in sensor availability on devices effectively limits the richness of the AR experience that can be achieved but this is hardware limited. GLARE itself utilizes mature API's that have wide compatibility including all types of headsets and interfaces as such by reducing constraints set in place to provide a level of usage for those not technologically savvy or lacking high end hardware. While these issues can interfere with the in-person AR experience, the virtual experience (which is native to any GLARE project) can be enjoyed remotely and remains similar across devices.

Limitations

The current study presents four main limitations. First and as mentioned above, the users involved with creation highlighted the need of a more user-friendly interface for avoiding technical issues in filling their own content. They also asked for more tutorials and customization features. Therefore, usability should be refined for maximizing GLARE's outcomes and usages. For addressing these requests, we will create a series of tutorials before the GUI release (which is planned to include customization features as well) and host a database of tours where users can add their own; this would become a content library for inspiration and free access. Regarding the AR May 4th testers, customization and content creation options are indeed features with remarkable potentials but also risks, from weakening the original experience to content filtering and supervision (e.g., materials that are not within the scope of AR tour). Therefore, curators must ponder them carefully during their design and production phases. Second, the automatization of the orientation of the overlaid image is still a technical challenge that requires adequate reflections and suggests a focus for future developments. Third, our evaluation relies on a small sample and, therefore, more studies are requested for shedding light on the platform's features and limitations.

Finally, the incarnation of the May 4th tour was restricted in the use of AR based on the defined application and target audience; however, GLARE's compatibility reaches far beyond what is included here. Current features not incorporated into the May 4th tour but accessible within GLARE include the ability to load 3D meshes at hotspots, hotspot groupings, multi-tour hosting, and using both device motion and orientation events to manipulate viewpoints. Additional features that are not included in the release, but have been used for alternate purposes and under development are:

1. The incorporation of AR markers for localizing AR content.
2. Incorporating real time pixel and lidar rendering within interface to embrace the future of dynamic scene mapping and object placement.

Further, we have already developed haptic interfaces to allow users to touch virtual objects and intend to incorporate these into the web platform in the near future. These features are possible due to the modular design of the tour and using high level libraries that provide simple access to hardware capabilities. These libraries provide access to XR headsets and controllers, allowing room scale mapping, interaction and beyond. The May 4th XR tour study design and desired outcomes would not benefit from these additional components and effort was taken to provide a widely accessible experience without technological overload. It is our sincere hope that the open-source approach to providing access to the tool, a simple method to add additional features and a *GitHub* repository will both track development of the project and allow other users to use, enhance and modify the project in the future.

CONCLUSION

This freely accessible AR framework was developed with a goal of presenting rich and interactive multimedia content at different physical locations by using a simple configuration system that does not require programming knowledge for customization. The user/creator experience was evaluated and proven to be an effective way to allow editors to use AR for developing their own experiences and engage users through a storyline (historical or otherwise) for informal educational settings and beyond. Further, the developed framework can be easily modified in the future to add additional features and provide additional augmented reality experiences.

GLARE can be easily extended and modified to refine and broaden the experience. For example, the underlying code base makes use of the *ThreeJS* programming interface to display overlaid imagery. This API is fully capable of rendering more advanced models, simulations or other types of computer-generated graphics. As such, by making a relatively small change in the codebase (~20 lines of code) a 3D model could be loaded at each GPS location and interacted with using the users' device significantly widening the potential applications of the framework. This could be extended to gameplay, or it could allow users to provide feedback at each hotspot for crowdsourcing or social media interactions.
More studies and analyses are needed to shed light on the AR framework's strengths and limitations, involving different audiences, subject areas, and instruments of inquiry. In addition, possible integrations and implementations regarding K-12 and higher education curricula should be investigated for developing proper pedagogies and lessons plans. In order to endorse such future efforts, GLARE is made available at https://glare.cs.kent.edu.

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