Toward Intuitive Understanding of Complex Astrodynamics Using Distributed Augmented Reality

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ABSTRACT

Existing capabilities and future possibilities can help multiple users build an intuitive understanding of complex astrodynamics in a collaborative real time virtual environment using an augmented reality (AR) space domain awareness (SDA) framework environment. This paper shows a range of state-of-the-art human computer interaction (HCI) capabilities that explore how novel data visualizations and modern display modalities enhance space education and SDA. The authors explain how augmented reality will be used in the near future to help educators, students, space professionals, scientists, and policymakers better understand the complex astrodynamics of resident space objects in support of learning, understanding, and decision making by space enthusiasts. The authors also explain how to use the capability on a practical level.

1. INTRODUCTION

To help educators, students, space professionals, scientists, and policymakers better understand the complex interactions of orbital mechanics, we developed the means to visualize and interact with the space domain in three dimensions (3D) using augmented reality (AR) in our space domain awareness (SDA) framework environment. AR is a form of virtual environment (VE) where the human interacts naturally in real time with both true reality and a synthetic overlayed reality model. This model of reality supports human interaction by collecting information from the model through ordinary human senses such as sight, sound, and touch and controlling the model using natural human actions such as gestures, voice, and head movements.

Effective models don't just translate traditional content or design guidelines to extended reality (XR), they also study the virtual work environment as a component of the overall system and use novel methods for early-stage prototyping and advanced prototype evaluation. Within our AR SDA framework, we apply psychophysical AR head-mounted display (HMD) limitations to inform device selection for context of use and display requirements, determining fidelity recommendations for virtual environments based on empirical experiments.

Our implementation approach uses cross-domain software development expertise informed by industry leading empirical research, human factors engineering, and key partnerships with users, researchers, and technology vendors. Our development approach leverages a portfolio of applied AR programs to develop tools and capabilities to enable more immersive, accessible, and intuitive AR, not just "toy" applications for entertainment value. This work is further enabled by a broader portfolio of multiplier technology—such as computer vision, machine learning, and data fusion—to support analytics and scenario development. Computer vision and machine learning expertise, for example, enhance XR applications beyond commercial off-the-shelf offerings with capabilities such as scene registration, recognition, and localization; fiducial marker tracking for better object tracking in VR; and custom gesture and speech recognition libraries for improved human-machine interface (HMI) reliability.

Custom AR engineering tools reduce development times and increase capability effectiveness. These include flexible interaction libraries for more ecologically valid HMI experiences in virtual environments, advanced haptic development and interface customization libraries, integrated hooks for distributed AR and live training, synchronous and asynchronous networking libraries to enable co-located and distributed virtual environment collaboration in AR, and massively scalable modeling and simulation capabilities to support persistent virtual environments.

Networked multi-user synchronized viewing supports co-located or distributed operators viewing the same content, such as for custom-built scenes for educational instructor/student interactions. User-driven scene annotations include free drawing in 3D space and custom 3D shape laydowns, such as sensor fields of view projected on the earth and 3D computer-aided design (CAD) models of satellites to let users zoom in to inspect their structure and makeup. This real-time 3D telestration supports the ability to annotate space objects, orbital trajectories, unusual conditions, and scenarios of interest.

Fig. 1 shows the three main use cases for the AR SDA framework environment in support of academic education. On the left, Scenario Development lets instructors design interactive context for lesson plans and student instruction. In the middle, Classroom-Based Networking lets educators and students share content in the virtual environment. Finally, Student Interaction lets students explore the virtual space to acquire a more intuitive understanding of orbits, interactions, and systems in space.

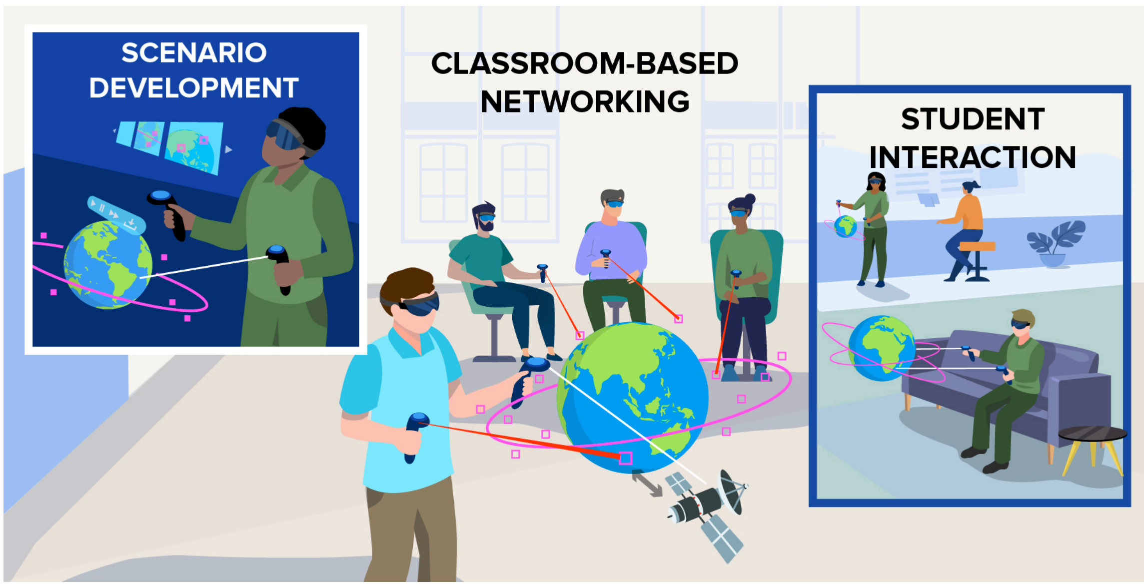

Fig. 1. Foundational capabilities enable effective, interactive educational experiences using augmented reality to build a more intuitive understanding of the dynamic space environment

Charles River Analytics developed the AR SDA framework environment under the DARPA Hallmark program. The framework was iteratively evaluated with professional space operators at 18 war-gaming events in simulated operations centers using real and synthetic data. It can be provided as a license-free solution with unlimited rights for Government usage. See https://www.cra.com/DARPA_Hallmark for information about the Hallmark program.

The framework environment provides AR to understand complex scenarios, including 3D volumetric visualizations to provide enhanced spatiotemporal understanding for proximity-based hazard assessments, maneuver planning, and scenario evaluations within a configurable virtual environment.

Synchronized AR overlays provide shared information overlays to user-level information access control, and the underlying 3D models support many AR and VR headsets, such as the Magic Leap One, Microsoft HoloLens 2, HTC Vive, and Oculus Rift-S.

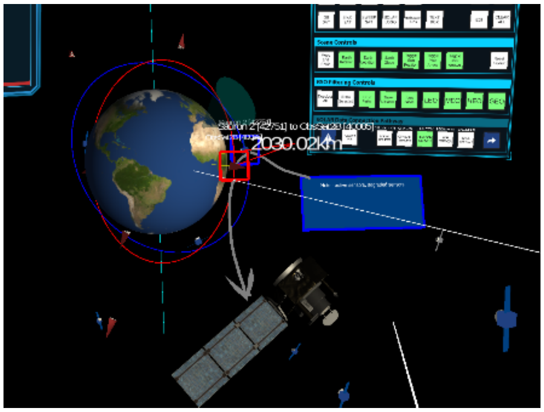

Fig. 2. Synchronized AR overlays provide user-level information access control and the ability to interact with various objects that represent the space environment

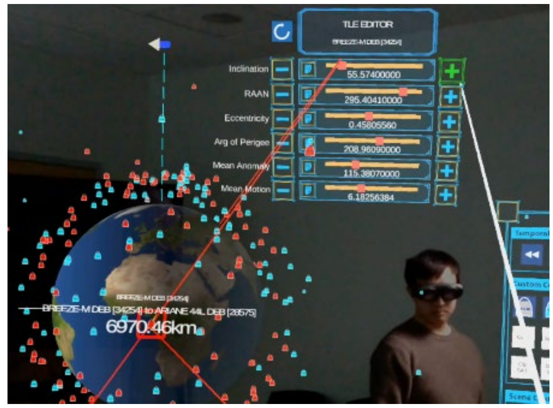

Fig. 3. AR solutions create a custom experience contextually tailored to individual needs to maximize effectiveness based on deep human factors expertise

The framework environment's spatiotemporal visualization capabilities increase individual operators' situational awareness (SA) for complex, multi-domain, inherently 4D battlespace concepts and develop and maintain shared SA among a classroom or operations floor. The framework is an AR application built in conjunction with a web-based desktop application for a variety of operational, tactical, training, and educational use cases. This framework enhances 3D visualization of 3D entities and spatiotemporal relationships, enabling custom annotation and planning, facilitating 2D and 3D briefing development, streamlining access to controlled information for specific users, and supporting co-located and distributed collaboration in shared 3D environments.

The educational AR environment is integrated with a 2D common operational picture (COP, shown in Fig. 4) that provides supplemental capabilities such as the ability to customize watchlists, send messages, and review AR screenshots using traditional computer monitors; this paper, however, will focus on the AR environment, which also stands alone as an independent capability.

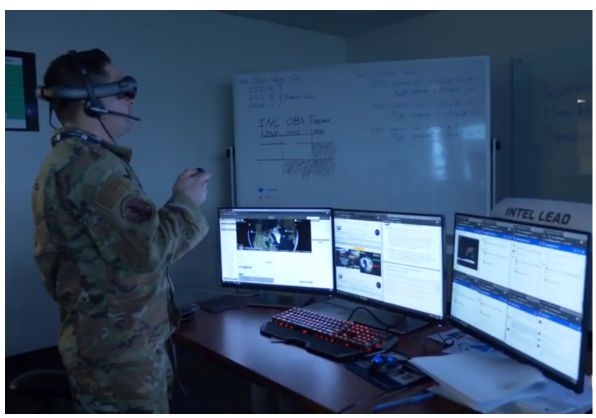

Fig. 4. Device and web networking with the common operating picture (COP), which enables collaboration, data streaming, configuration, and 3D content sharing

Our AR SDA framework environment is built on Charles River Analytics' commercial open-source VIRTUOSO product to provide common, flexible, and extensible front-end workflow and visualization support for collaborative use and is proven to enhance space operations education and training. The AR educational environment builds on Charles River's open-source VIRTUOSO Software Development Kit (VSDK) (see http://cra.com/projects/virtuoso and http://cra.com/vsdk).

2. SOLUTION ARCHITECTURE

The AR capability enables users to observe and interact directly with the space enterprise via applied AR for 3D spatiotemporal visualization. Users can literally walk around the virtual globe and through satellite orbits to see their shapes. Users can see and interact with two-line element (TLE)-based resident space objects (RSO) and their orbital paths, and they have the ability to rewind and fast forward projected RSO positions on their estimated orbits. They can toggle between earth-centered, earth-fixed (ECEF) and earth-centered inertial (ECI) coordinate frames and also dynamically edit TLEs in the VE to understand the effect of parameter changes to orbital trajectories. Through configurable content positioning, orientation, and scaling, users can reposition the globe and selected orbits to better understand their properties.

Fig. 5 details how this AR SDA framework environment addresses unmet space education and training needs with three functional components: (1) a Dynamic Scenario Suite with tools for development, interaction, and lesson archival; (2) a Space Education Engine with core space education content, tools, and interaction systems; and (3) a Networking Architecture for Cross-device synchronous networking support for education-based use.

The Dynamic Scenario Suite includes in-XR scenario scripting tools (e.g., temporal controls, camera view controls, text and free-form annotations, storyboard editors), XR- and web-accessible libraries of saved scenarios, lesson and course plans, and student-saved work, and configurable "lab mode" for students to interact with XR education content outside of the classroom by walking through scenarios and decision outcomes.

The Space Education Engine includes 4D geospatial data and relationship visualization (e.g., satellite tracks, ground assets, space weather), manipulation tools to dynamically interact with digital entities (e.g., TLE editor, ground station editor), and user controls to toggle and customize user content and views (e.g., zoom).

Finally, the Networking Architecture includes three display or networking modes: (1) projection mode displaying the instructor's point of view (POV) on individual student HMDs, (2) classroom mode displaying one virtual globe in the center of the classroom, and (3) collaboration mode enabling students to work in groups on the same virtual assets in real time.

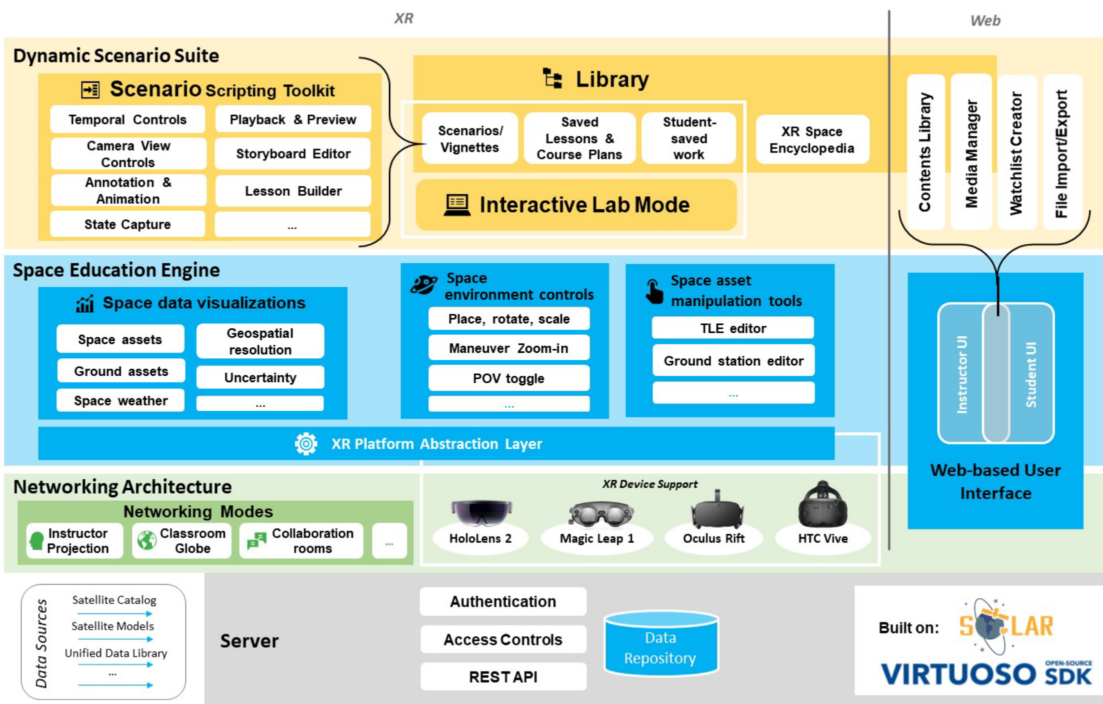

Fig. 5. Augmented reality (AR) space domain awareness (SDA) framework environment

Fig. 6, Fig. 7, and Fig. 8 show representative screenshots of the AR capability in use.

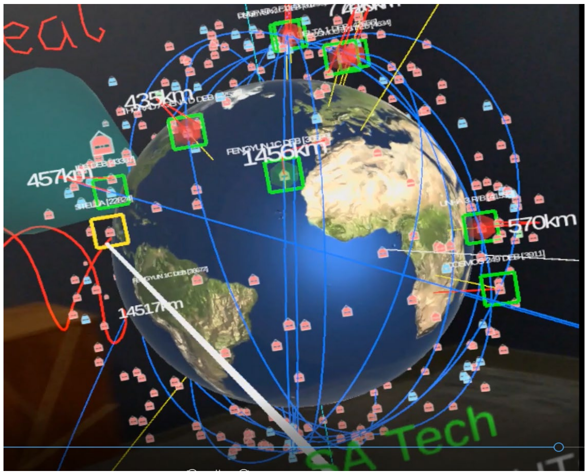

Fig. 6. AR overlays highlight specific watchlist satellites (such as a constellation in green boxes) and show orbital paths

Fig. 7. Visualization of space asset locations relative to Earth, nearby objects, and accurate ranges provide context of scale

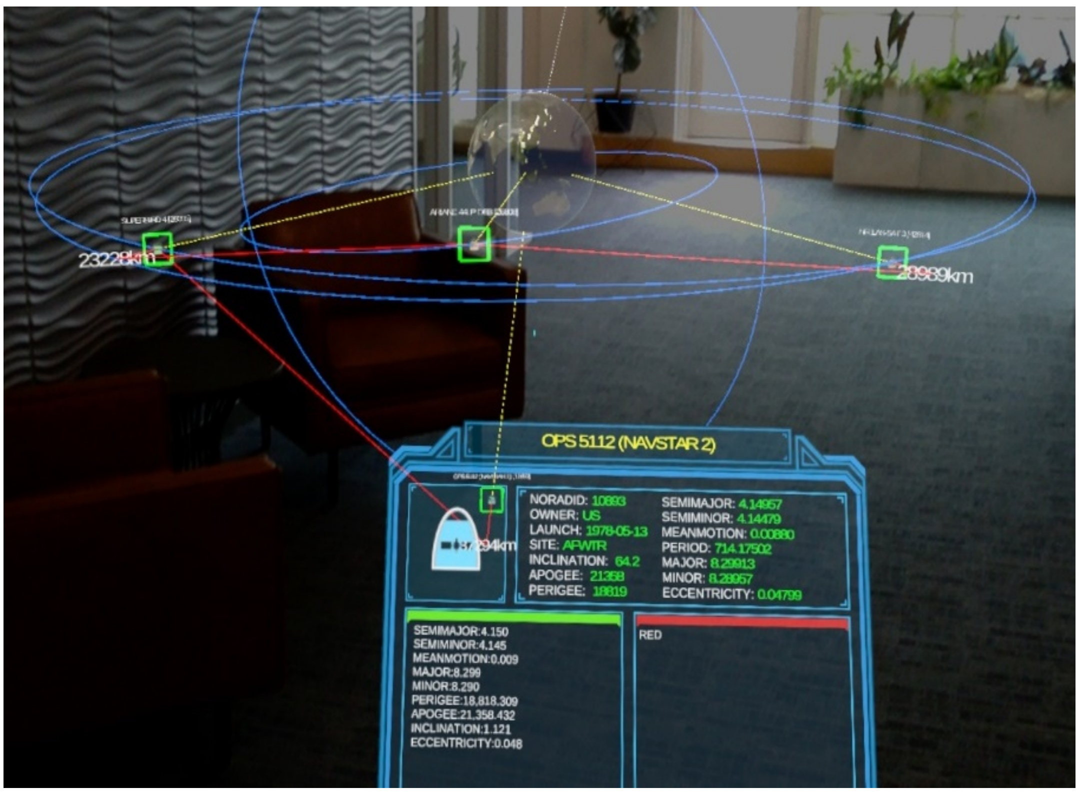

Fig. 8. Networked AR orbital visualization promotes shared SA through collaborative virtual spaces

While navigating the virtual environment, users can reference additional information panels for more context. The "Spaceball Card" on the bottom of Fig. 8 provides additional detail and specific notes about a selected satellite. With networking enabled, students or instructors can update notes for specific assets using the companion web application. The RECENT RSOs panel on the right of Fig. 9 shows the names and information of the last five RSOs, or resident space objects, selected. When selected in the list, the specific asset will be highlighted within the scene.

Fig. 9. Metadata information panels provide in-situ context about custom watchlists, specific RSOs, and their orbital parameters

The current implementation of the AR SDA framework environment is compatible with the Magic Leap One and Microsoft HoloLens 2 AR headsets, as well as the HTC Vive and Oculus Rift-S VR headsets, shown in Fig. 10.

HTC Vive Headset

Microsoft HoloLens 2 AR Headset

Oculus Rift-S Headset

Magic Leap One AR Headset

Fig. 10. Virtual reality (VR) (left) and augmented reality (AR) (right) headsets

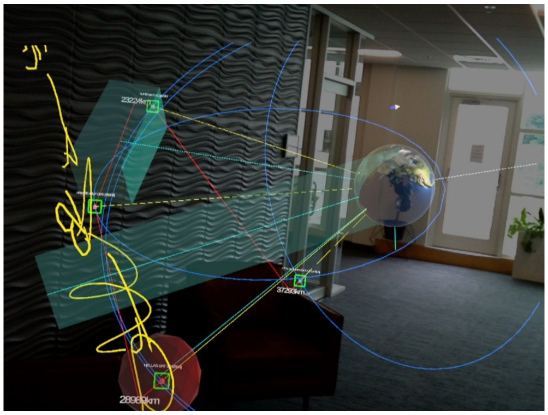

Fig. 11. Custom telestration annotations can be drawn in the 3D environment and shared among instructors and students to facilitate concept understanding and mastery

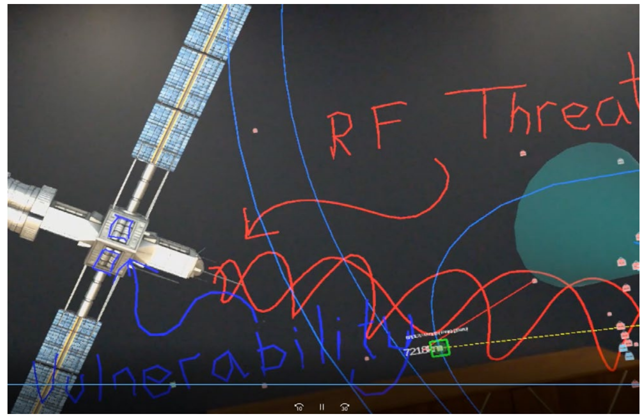

Fig. 12. Scalable 3D models provide realistic walk-through models of spacecraft to enhance understanding of on-orbit capabilities, limitations, and maneuver control options

3. INTERFACE NAVIGATION

This section provides a description of each button on the AR SDA framework environment control panel (Fig. 13) to both show the full capabilities of the tool and to support readers in using the capability.

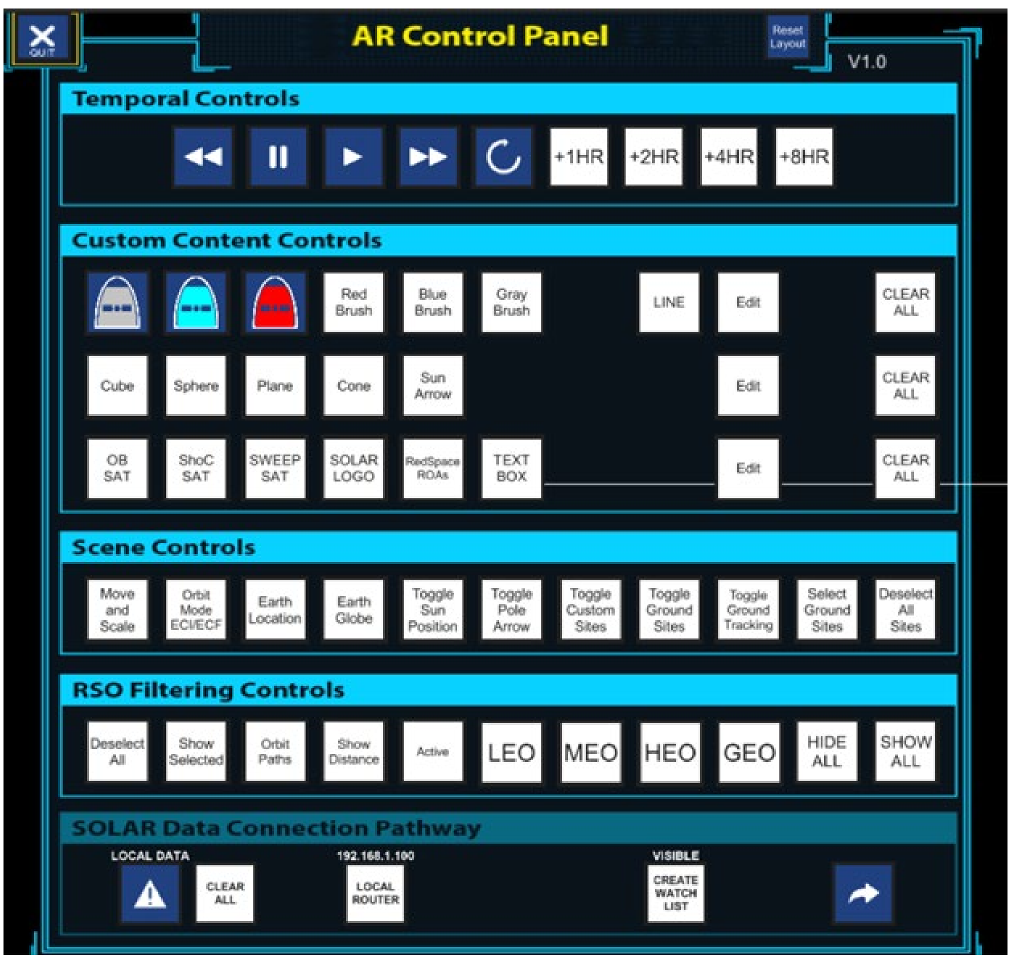

Fig. 13. AR SDA framework environment control panel

The application controls, shown in Fig. 14, include Quit and Reset Layout options. Quit will fully quit the application. You can also close the application by pressing and holding the Home button on the controller; however, this only *closes* the application, rather than *quitting* the application. To fully quit, you must press and hold the Home button again and quit there. Reset Layout will automatically reset the layout of all the panels in the scene based on the location of the Control Panel. A user can press "Reset Layout" to snap all of the panels directly in front of them.

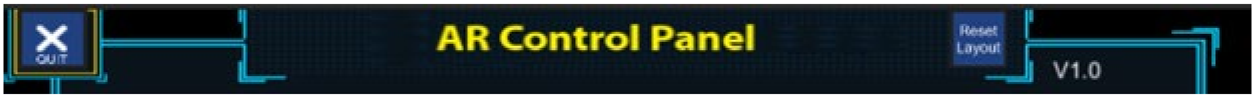

Fig. 14. Control Panel application controls

The Temporal Controls row includes buttons to control the speed and timeframe of the satellite data you are visualizing. These controls are also available by hovering above the globe, and they include Rewind, Pause, Play, Fast Forward, and Reset. Rewind will reverse the timeframe in which you are visualizing data. Press this button multiple times to increase the rate at which you rewind and hold up your controller in front of you to see the rate at which you are rewinding. The Pause button will pause the playback of data, and the Play button will play or resume data playback. You can also press the bumper button on the controller to quickly pause or play the satellite data. The Fast Forward button will advance the timeframe in which you are visualizing data. You can press this button multiple times to increase the fast-forwarding rate and also hold up your controller in front of you to see the rate at which you are fast forwarding. The Reset button resets the timeframe to the current day and time, and the +#HR buttons are shortcuts to skip time ahead in specific 1-hour, 2-hour, 4-hour, or 8-hour increments.

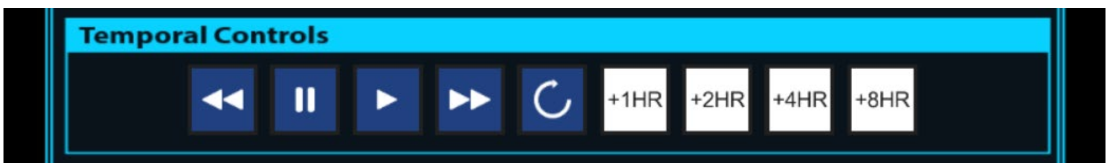

Fig. 15. Temporal Controls

Custom Content Control buttons, shown in Fig. 16, are used to create, edit, and delete custom annotations and content in the scene. These buttons include satellite icons, brushes, Line, Edit, and Clear All. If the white "laser pointer" beam is not visible coming from the controller, then you are in an editing/annotation mode. Press the bumper to clear out of any annotation mode and your laser pointer should return.

The gray, blue, and red satellite icons are used to place notional satellites into the scene. You do this by pointing and selecting a button once with the trigger so it appears on the front of your controller. Next, use the controller as if it were a stamp to place and drop (by pressing the trigger) the icon within the 3D scene. Finally, press the bumper button to clear out of this placement mode.

Brushes let you free draw within the 3D scene. Begin by pointing and selecting a brush color button once with the trigger, so that the button flashes and the laser pointer disappears. Next, use the controller as if it were a marker and hold down the trigger to free draw in 3D within the scene using the chosen color. Press the bumper again to clear out of this drawing mode.

The Line button lets you toggle to draw a straight line. First, point and select the button once with the trigger so that it turns green to indicate that straight line mode is enabled. Next, select a brush color and use the controller as if it were a marker by holding down the trigger and moving the controller to draw a straight line into the scene. Your first trigger pull is the starting point of the line, and your trigger release will be the ending point of the straight line. Point and press the Line button again to turn off straight line mode.

Turn on Edit mode to make the objects and drawings that you added to the scene editable. By pointing your controller at these objects, they will pulse to indicate that you have highlighted them. Press the trigger to grab the object again and move it elsewhere or press the bumper to delete the selected object.

The Clear All button will clear all the objects and annotations in the scene that correspond with the controls in that given row. Note: each "Edit" and "Clear All" button only applies to the objects/annotations within the same row on the AR Control Panel.

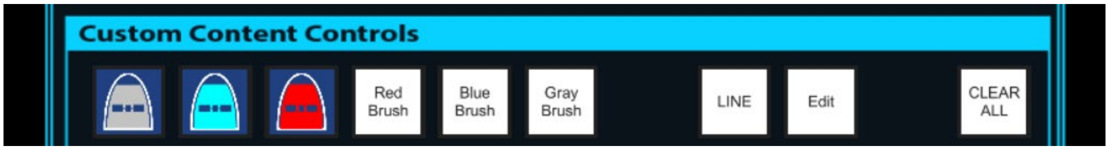

Fig. 16. Custom Content Controls

3D shapes let you place Earth-referenced 3D shapes such as cubes, spheres, planes, cones, and reference arrows into the scene (see Fig. 17). To do this, point and select a 3D shape type so that it appears by the front of your controller with a line extending from the center of the shape to the center of the globe. While holding the shape, scale the shape size by pressing down on the left and right sides of the touchpad. Move your controller around the space to adjust the placement of the object and press the trigger to release the object where your controller is located. Press the bumper to clear out of this mode. The Sun Arrow shape behaves differently, in that it is a 3D arrow that will always point toward the direction of the sun, and there is no line from the center of the arrow to the center of the earth.

Fig. 17. 3D shape controls

3D objects that can be added and manipulated include various representative satellite models, logos, and text boxes (shown in Fig. 18). Use the Edit button in this row to edit the placement or content of models and text boxes.

The satellite models place high fidelity 3D CAD models of notional satellites into the scene. To do this, first point and select one of the three satellite models so that it appears at your controller. While holding the shape, scale the satellite model size by pressing down on the left and right sides of the controller touchpad. Move your controller around the space to adjust the placement of the object and rotate the controller in your hand to see different views of the model. Finally, press the trigger to release the object where your controller is located and press the bumper to clear out of this placement mode. To place a logo into the scene, use the same steps as with satellite models.

With the Text Box, you can free type text using a Bluetooth keyboard anywhere within the scene. First, point and select Text Box, and while holding the textbox, scale its size by pressing down on the left and right sides of the touchpad. Press the trigger once to freeze the size of the textbox and place it in the scene so that the border of the textbox turns yellow. While the border is highlighted in yellow, use your Bluetooth keyboard to type free form text. Once you are done typing, press the trigger again so that the textbox border turns blue and the textbox is no longer editable.

Fig. 18. 3D Object Controls

Scene Control Buttons, shown in Fig. 19, toggle different modes or visualizations within the scene. These include Move and Scale, Orbit Mode, Earth Location, Earth Globe, Toggle Sun Position, Toggle Pole Arrow, Toggle Custom Sites, Toggle Ground Sites, Toggle Ground Tracking, Select Ground Sites, and Deselect All Sites.

Move and Scale mode lets you move and scale the AR panels and globe anywhere within your environment. This mode is active when the control panel button is green and when you point to a panel or globe and a green highlight with the object name appears. In this mode, press the trigger once to select an object and use the touchpad to scale the size (left/right) and the distance (up/down) at which the object is placed in the scene. Press the Move and Scale button again to exit this mode and it will turn from green to white.

In Orbit Mode, you can toggle between the earth centered inertial (ECI) and earth-centered earth-fixed (ECEF) reference frames and coordinate systems. The difference between the two views is most apparent when viewing TLEs. You should turn this toggle on when using the TLE editor. The Earth Location mode toggles visualization of the yellow line from a selected asset to the earth, and the Earth Globe mode toggles visualizations of the earth globe. Toggle Sun Position enables and disables the white line extending from the earth to the location of the sun. Toggle Pole Arrow toggles visualization of the 3D sun arrow at the top of the blue line extending from the pole of the earth. The Toggle Custom Sites button enables visualization of any custom ground sites on the earth that were created using the Site Editor, and the Toggle Ground Sites button similarly toggles all ground sites on the globe, including both pre-programmed and custom sites. Toggle Ground Tracking enables visualization of the blue lines from the selected satellite to ground stations within a set distance of the space asset's footprint. Select Ground Sites hides all space assets and only displays the ground sites on the earth globe. While in this mode, you can select a ground site and use the Site Editor to edit it. When a ground site has a green highlight box around it, it is editable. When it has a yellow highlight box around it, it is still selected but not currently editable. If you turn this mode off and still do not see satellites, press the Show All button in the row below and the satellites will reappear. The Deselect All Sites button will immediately deselect all ground sites currently selected to unclutter the scene.

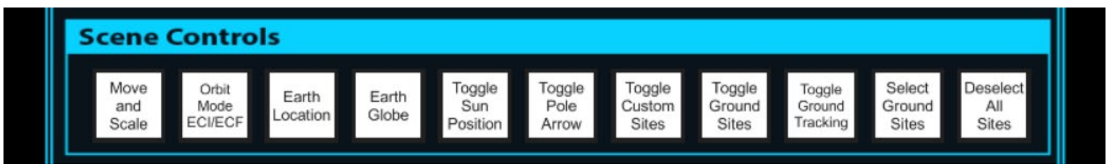

Fig. 19. Scene Controls

The RSO Filtering Controls, shown in Fig. 20, are used to filter the satellite content and related visualizations within the scene. These include Deselect All, Show Selected, Orbit Paths, Show Distance, Active, four different orbital regimes, Hide All, and Show All. Deselect All will quickly deselect all selected assets in the scene to reduce clutter. Show Selected filters your view to show only the assets that are currently selected. To quickly create a watchlist of your selected assets, press Show Selected and then press Visible: Create New Watchlist while in offline mode. Orbit Paths toggles visualization of the TLE orbit paths of selected assets. Show Distance toggles visualization of the distance between the selected asset and the next closest asset. The All/Active/Inactive toggle button filters your view between all satellites in the catalog, only active satellites in the catalog, and only inactive satellites in the catalog. Green dots represent active satellites and gray dots represent inactive satellites. Orbital regimes (i.e., LEO, MEO, HEO, GEO) filter your view to show assets in only the specific orbital regimes. Hide All will remove all space assets from your view, and Show All recovers all space assets in the scene into your view. When switching between site editing, TLE editing, and watchlists, this is a quick way to reset the data and bring all assets back into view

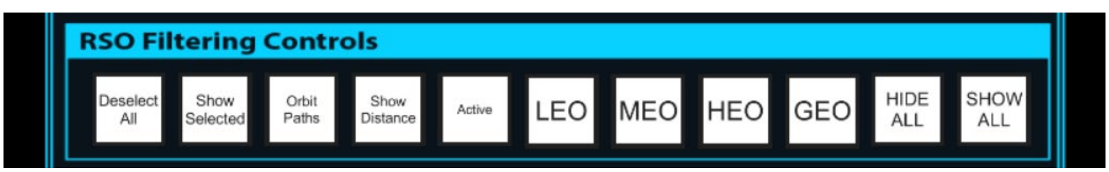

Fig. 20. RSO Filtering Controls

The Data Connection Pathway has a few ways to load or remove data from the AR or VR device, namely Clear All, Local Router, Create Watchlist, and Push (Share). Clear All will clear all the loaded asset data from the scene. After pressing Clear All, you will need to reload the data into the scene by selecting Local Data or Local Router. Local Data will load and display the locally saved Space-Track and CelesTrak satellite and TLE catalog data preloaded on the headset, which includes about 20,000 assets. Use this data when you do not have the headsets networked to the server. If you manually saved custom watchlists or TLEs to the headset, they will only appear when Local Data is turned on (i.e., when you are in offline mode). Local Router will connect the headset to the network, such as to the SOLAR web application, the SOLAR server, and other Magic Leap headsets on the same network. Before pressing this button, make sure your computer is on and the local SOLAR web application is running. Visible: Create Watchlist quickly creates a watchlist in offline mode by saving the assets currently in view (i.e., visible) into a prenamed watchlist in the Watchlists panel. Push (Share) will push your custom annotations and other custom content (e.g., custom TLEs) associated with a specific Watchlist to the network to enable other users to see the same custom content.

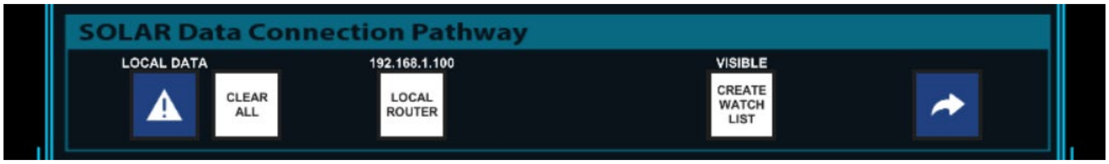

Fig. 21. SOLAR Data Connection Pathway

4. FILTERING

The Watchlists Panel provides a list of Watchlists, which are custom-defined groups of assets. The user can toggle these Watchlists to visualize the assets it contains in the scene (one at a time or combining multiple at a time). In offline mode, you can create Watchlists by using the Visible: Create Watchlist button in the Control Panel. You can delete specific Watchlists that you created in offline mode by pressing the trash icon to the left of the Watchlist. You can only delete Watchlists from within AR when using offline mode. You cannot delete Watchlists from within AR when you are networked and using data from the SOLAR server. Rather, you must delete Watchlists from the web application. In networked mode, the Watchlists panel will populate with all the Watchlists from the SOLAR web application that are “flagged for AR user.” You can refresh the content of the Watchlists, as well as any custom annotations tied to the shared over the network, by hitting the Refresh button on the Watchlists panel.

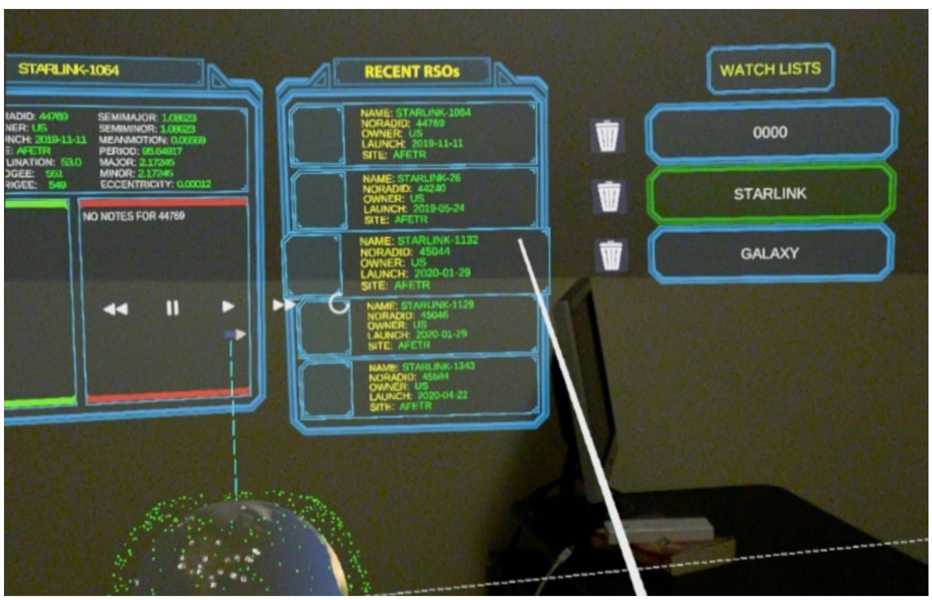

Fig. 22. Watchlists Panel

Search Panels let users filter and locate specific assets. Name Search dynamically filters the assets in view by name as you type. For example, if you type in starlink, you will only see the satellites in the StarLink constellation. If you are in offline mode and want to quickly access this constellation, after filtering to this view, you can hit Visible: Create Watchlist in the Control Panel and create a StarLink Watchlist, which will then appear in the Watchlist panel. RSO Search lets you type in a specific NORAD ID and press the magnifying glass to select and highlight the specific asset in the AR environment.

Fig. 23. Search Panel

5. ORBIT EXPLORATION

The built-in TLE Editor allows you to visualize dynamic manipulation of an existing orbit and create new TLEs by making a copy of an existing orbit, manipulating it across six different orbital elements, and then saving the new state.

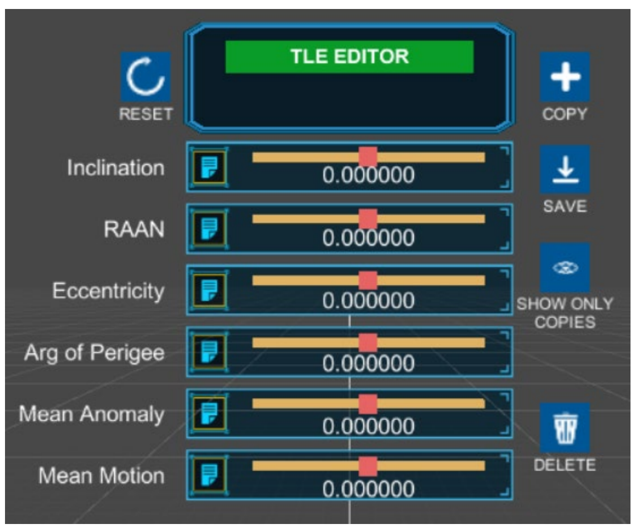

Fig. 24. TLE Editor

Start by selecting an RSO of interest. To make sure you only have one asset selected, press Deselect All in the Control Panel to quickly clear your selection. You can also press Show Selected in the Control Panel to quickly filter out the noise and focus on one asset and orbit. Next, select one of the six sliders so that it highlights green—this is the orbital element that you will be manipulating. While highlighted, use the left and right side of the touchpad to dynamically shift the slider and look at the orbit to visualize how it changes. If you have a Bluetooth keyboard connected, you can type in a specific value while an orbital element slider is highlighted green. To reset to the original TLE, press the Reset button (circular arrow) in the upper left corner of the TLE Editor.

To create a new TLE, select an existing asset and press the Copy button (+ icon) in the upper right corner. Once copied, use the orbital element sliders/fields to directly manipulate the parameters of the TLE. To save the copy as a new TLE, press the Save button (arrow pointing down icon) on the right. This will save as a file on the headset called saved-tles.txt. Press Show Only Copies to filter the scene to only show the custom TLEs added to the scene. While a custom/copied TLE is selected, you can press the Delete button (trash icon) to delete it. Fig. 25 show an example manipulation of an orbital element using the TLE Editor.

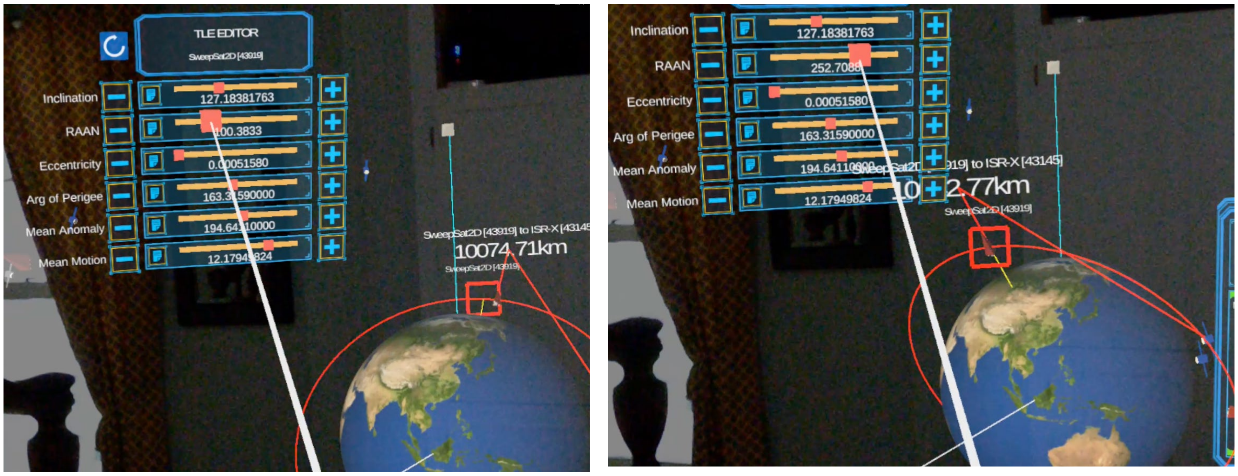

Fig. 25. SDA Framework Environment's two-line element (TLE) editor

6. SYNCHRONIZED OVERLAYS

The Ground Site Editor (Fig. 26) allows you to edit the existing ground sites on the globe and create and save new ground sites. Press Select Ground Sites on the Control Panel to quickly filter out space assets and enable you to select existing ground sites on the globe. Point and select one of the existing ground sites on the globe and the Site Editor will update to reflect the data specific to that site. Use the Site Editor to edit and adjust the parameters and coding of the site as you wish. Press the Reset button in the upper left to reset the ground truth data of the site, or select the New (+ icon) button in the upper right to create a new ground site. Select Longitude, Latitude, or Altitude (the active selection will highlight green) and use the controller touchpad to shift the slider to the left and right and move the location of the site. You can also use a paired Bluetooth keyboard to type in a specific value for each of these three parameters while each slider is highlighted green. Select the Name field and use a paired Bluetooth keyboard to enter a name for the site, and then assign site one of six icons (C2 for Command and Control, Laser, Mobile, Optic, Radar, Signal, or Spaceport) to indicate what the site represents. Finally, assign the site a color (red, blue, or gray) and press the Save button on right to save a custom ground site in the system. You can also press the Toggle Custom Sites button on the Control Panel to filter to view only your custom ground sites. While a custom site is selected, you can press the Delete button on the right of the panel to delete it.

Fig. 26. Ground Site Editor

The Media Manager lets students and instructors quickly share screenshots taken in AR to the 2D web interface. To use the Media Manager, first make sure the AR headset is networked with the SOLAR Server and web application. While wearing the AR headset, take a screenshot of your view by pressing the home button on the controller once. The screenshot will only capture the digital content in your view and replace the background with black.

In the SOLAR Web application, navigate to the "Media" tab in the header and the page will chronologically display all of the screenshots taken in the AR headset, starting with the most recent. Each screenshot will indicate the user who took the screenshot and how long ago the screenshot was taken. You can select the thumbnail to download the image to your computer and use the icons at the upper right of the screenshot to edit or delete the screenshot.

You can also record videos and take photos using the native AR media capture feature. Press and hold the home button and then press and hold the bumper button. This will open an on-screen menu to take a photo or record a video. This media capture includes the real-world background of the environment in which you are using the AR headset.

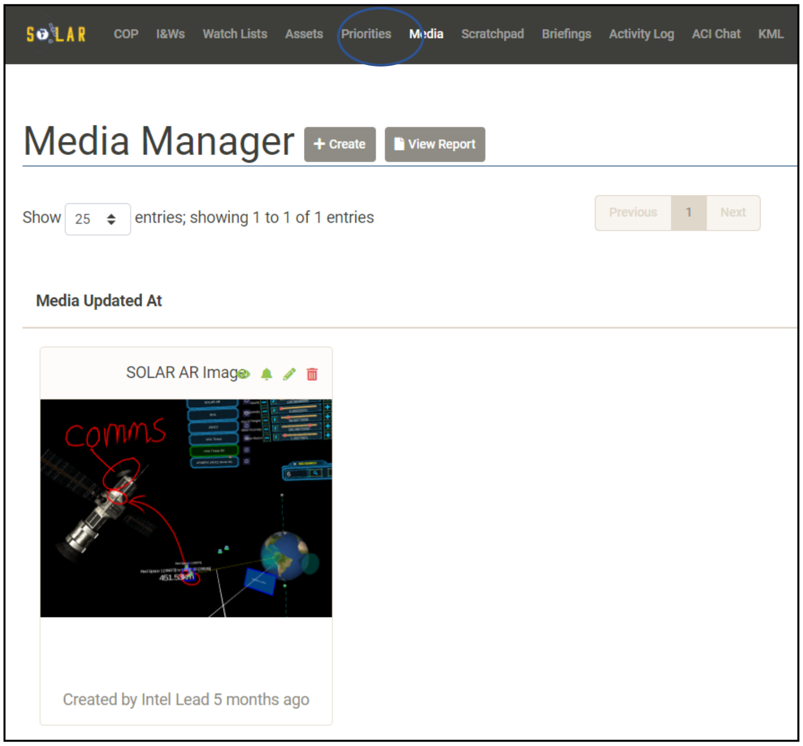

Fig. 27. Media Manager

7. CONCLUSION

Charles River Analytics' AR SDA framework environment provides a high-fidelity world and orbit model for any type of user, ranging from space operators and decision makers to primary and secondary students. Space is complex; it truly is rocket science. To better understand this new frontier, we must be able to visualize and simplify tactics, techniques, and procedures (TTPs); design new concepts of operation (CONOPS), and identify and understand the relationships of objects in space. Our framework allows students to extend their knowledge through customizable plug-ins, scenario development, and interactive in-situ experience. We plan to expand our current orbital mechanics with more features, implement more robust XGEO capabilities, and integrate data sources such as ASTRIAGraph and the Unified Data Library (UDL).

Our AR SDA framework provides a baseline for accessible space education for all ages and education levels. The ability to see and walk around the earth while in a classroom, operations center, or at home provides a dynamic, engaging experience to better understand the near-earth environment.

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