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The Accelerated User Reasoning for Operations, Research, and Analysis (AURORA) Cross-Reality Common Operating Picture

by Mark S Dennison and Theron T Trout

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14. ABSTRACT

AURORA stands for Accelerated User Reasoning for Operations, Research, and Analysis and is a research platform consisting of server, network, and interface modules. AURORA was designed to enable experimentation on the ingestion of battlefield data on a configurable network, along with its visualization, analysis, and actuation by human–agent teams that are colocated and distributed. AURORA's purpose is to address the fundamental Army need for a common operating picture (COP) that supports multidomain operations (MDO). The construction and optimal function of such a COP depends on the Warfighter's role, connectivity to information and computing resources, and need for situational awareness. The future COP must be aware of the state of users, the state of the network, and the state of the battlefield to seamlessly adapt accordingly. However, changes to existing operating dynamics to support MDO command and control will require a comprehensive evaluation of any new technologies or techniques; interoperability across systems remains a significant challenge. AURORA seeks to provide researchers with an integrated environment to study human–information interaction and interoperability and intelligent information processing. This report details the design of each of AURORA's modules, proposed additional features, and research topics to evaluate the effectiveness of AURORA in achieving these goals.

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cross-reality, virtual reality, common operating picture, human–information interaction, network, server, command and control

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1. Overview of AURORA

AURORA stands for Accelerated User Reasoning for Operations, Research, and Analysis and is a research platform consisting of server (AURORA-Server), network (AURORA-Net), and interface (AURORA-XR) modules. AURORA was designed to enable researchers to study the visualization, analysis, and actuation of battlefield data across multiple domains by collaborative teams of humans and intelligent agents that are both colocated and distributed over geographical space.

The purpose of AURORA is to address the fundamental Army need for a common operating picture (COP) that enables enhanced and rapid command and control (C2) in future multidomain operations (MDO). The construction and optimal functionality of such a COP depends critically on the Warfighter's role, connectivity to information, computing resources, and need to scan for threats (situational awareness). The future COP must be aware of the state of its user, the state of the network, and the state of the battlefield to seamlessly adapt itself accordingly. However, changes to the existing C2 operating dynamics in the new MDO space will require a comprehensive evaluation of any new technologies or techniques; interoperability across disparate systems remains a significant challenge.

This report details the design of each of AURORA's modules, proposed additional features, and open research topics to evaluate the effectiveness of the AURORA system in achieving these goals.

2. Introduction

2.1 Immersive Technology for the Future COP

Virtual reality (VR), augmented reality (AR), and mixed reality (MR) offer users new methods to access, consume, and interact with information. AURORA and its subcomponents offer ways to support and enable novel human–information interaction research. The differences among VR, AR, and MR are shown in Fig. 1. Collectively, these systems are often referred to as cross-reality (XR) technology. However, the term "cross reality" may also refer to an immersive experience where synthetic or virtual information is directly linked or representative of a physical thing out in the real world.

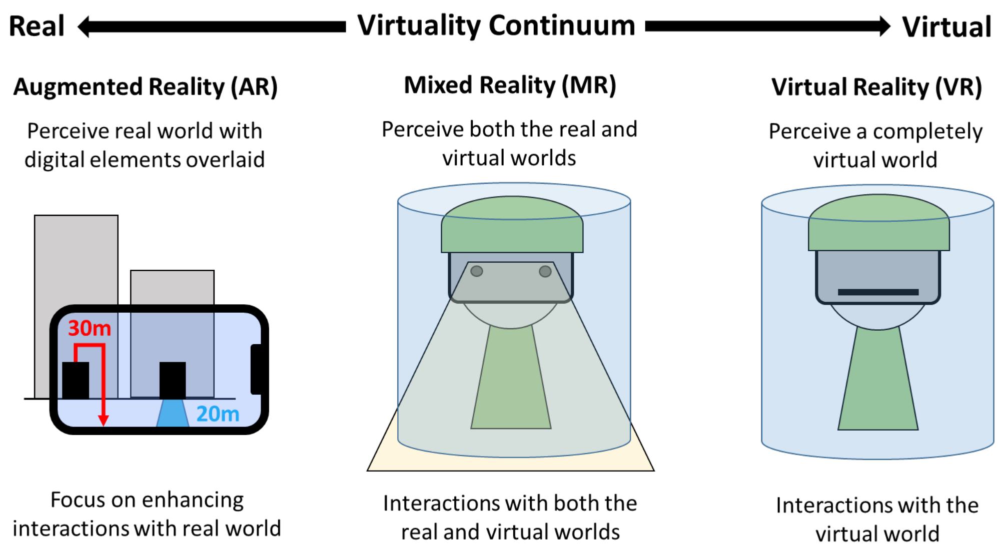

Fig. 1 Differences among AR, MR, and VR immersive technologies

The future COP has the potential to provide a unified information environment where decision-making can be distributed across devices and echelons optimally. XR systems also allow for collaborative yet distributed mission intelligence and C2 operations while mitigating the constraints and risks of traditional systems. This technology has the potential to connect commanders and analysts to battlefield information across echelons and empower decision-making to enable overmatch.

2.2 Objectives of AURORA

Current research in immersive analytics is limited, and optimal methods for using cross reality in military decision-making are not yet well established. Commercial off-the-shelf XR software, such as the Unity and Unreal engines, make it difficult for researchers to natively explore the realm of problems associated with immersive human–information interaction in operational and tactical scenarios. A substantial weakness of these systems is an inadequate, or unmodifiable, networking and server solution that allows researchers to fully manipulate the space.

The primary objective of AURORA is to provide researchers with an ecosystem that enables the study of multiuser collaborative decision-making with secure connectivity to heterogeneous data visualized across immersive and nonimmersive display modalities. AURORA thus consists of three major components.

First, AURORA-Net investigates ways to provide operators with secure and reliable network connectivity over both constrained tactical networks as well as high-performance links. Second, the AURORA-Server explores methods of coordinating multiuser, XR environments to enable COP capabilities over a resilient, self-healing mesh network of servers that can adapt to dynamic battlefield network conditions. Finally, AURORA-XR allows the adaptive presentation of information from the AURORA ecosystem to Soldiers based on the interface used and their background, mission needs, and internal state. AURORA seeks to support the full spectrum of the XR continuum, ranging from VR command environments to AR tactical systems, such as the Army's Integrated Visual Augmentation System.

3. AURORA Components

3.1 AURORA-Server

The AURORA-Server is the primary communication broker interconnecting AURORA client systems and external data interlinks. Individual AURORA-Servers will discover and connect to one another to provide federated services. Implementation of the federation capability is ongoing and is envisioned to operate in the following manner.

Consider a dismounted squad on patrol. Each Soldier would have a small, lightweight, and low-power AURORA-Server on their person. Their AR headset and other devices would connect to their personal server. Each Soldier's server would connect to those of the other Soldiers in the squad. The servers would elect a leader server node that would provide coordination and synchronization among the others. As the Soldiers perform their patrol, they may come within range of an unmanned aircraft system also running an AURORA-Server node. The local squad AURORA-Server cluster could establish a federated link to this platform, obtain real-time sensor data, and leverage any uplink connectivity it might have to provide AURORA-Net-based communication with their commanders at the tactical operations center (TOC) and other remote locations.

The AURORA-Server is designed to operate as a collection or swarm of small components, each providing a specific capability in an atomic fashion. This makes the AURORA-Server well suited for scalability and also has demonstrated self-healing characteristics. The server was developed in Docker Swarm and is well suited for building large service clusters such as Kubernetes or in cloud environments that possess self-healing capabilities. For example, when certain components have failed, they shut down and restart, thereby restoring the impacted capabilities without requiring reset of the entire network. The limiting factor is the network and CPU performance of the brokers that interconnect the worker components.

3.2 AURORA-Application Framework

The AURORA-Application Framework (AAF) provides the connectivity layer between AURORA and external data sources and computational services. AAF provides service discovery and utilization throughout the federated architecture. Applications may utilize both publish/subscribe (pub/sub) data distribution as well as remote procedure call-request handling.

3.3 AURORA-Net

AURORA-Net provides the encrypted communication layer connecting AURORA nodes to one another (Fig. 2). The first-generation AURORA-Net is built using ZeroMQ with elliptical-curve cryptography and public/private key infrastructure for authentication via CurveMQ. ZeroMQ provides a high-performance transport that is shown to work well on both low-bandwidth-constrained and high-performance networks. Future versions will likely add support for other communication protocols, such as MOCKETS, and so on, to optimize link utilization and further enhance robustness for operations over constrained, tactical networks.

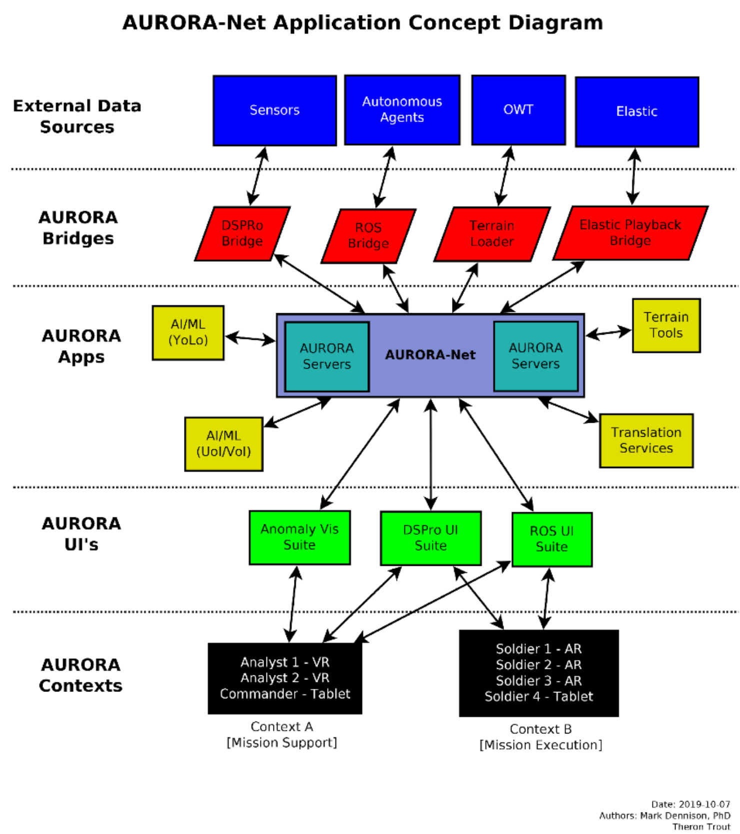

Fig. 2 Methods of interconnectivity of components of AURORA as enabled by AURORA-Net

3.4 AURORA Contexts

In physical operations centers, different stations or rooms are often used to separate the activities of, for example, the analysis of financial intelligence from sensor intelligence. In the virtual world, the concept of a “room” is inadequate to fully capture the capabilities of such virtual “spaces.” Therefore, we have implemented the concept of AURORA Contexts.

An AURORA Context represents a particular topic, mission, analysis requirement, and so on. For example, consider the scenario of a TOC using an adaptive COP to track the position and status of friendly assets. Some of these assets are real and some of them are spoofed. One AURORA Context could be used to see the battlefield from the perspective of friendly forces, whereas another Context could be used to show the predicted view of the battlefield from opposing forces.

AURORA applications can communicate information over AURORA-Net on one or multiple Contexts as desired by the user. Currently, Contexts must be created before deployment of the system, but system users will be able to create Contexts dynamically to suit mission needs.

3.5 AURORA-XR

3.5.1 Overview of AURORA-XR

AURORA-XR is the interface module of the AURORA ecosystem and serves to provide users with a means of perceiving and interacting with battlefield information from heterogeneous sources, as well as interacting with other colocated and remote users. Data can either be locally generated (as in simulation) or, more optimally, taken from data feeds on the AURORA network that are subscribed to by applications running within an AURORA-XR-enabled device.

AURORA-XR interfaces are built on an application programming interface (API) for the Unity engine by Unity Technologies (San Francisco, California). Any display technology that is supported by the Unity engine may be developed into an AURORA-enabled system. Currently, the system supports a Windows PC with an Oculus Rift S or Oculus Rift (CV1) (Oculus VR, Irvine, California) head-mounted display (HMD). Future development to support the Oculus Quest and Microsoft HoloLens (Microsoft Corporation, Redmond, Washington) are planned, as well as 2-D tablet and desktop versions.

3.5.2 AURORA Server, Authentication, and Context Selection

Upon starting the AURORA-XR system with the HMD, the user is placed into a virtual lobby where they are shown the server selection screen, as shown in Fig. 3. On this screen, the user is able to select a server and an appropriate server public key. The user is also able to select if they want to use the system offline and not connect to an AURORA server.

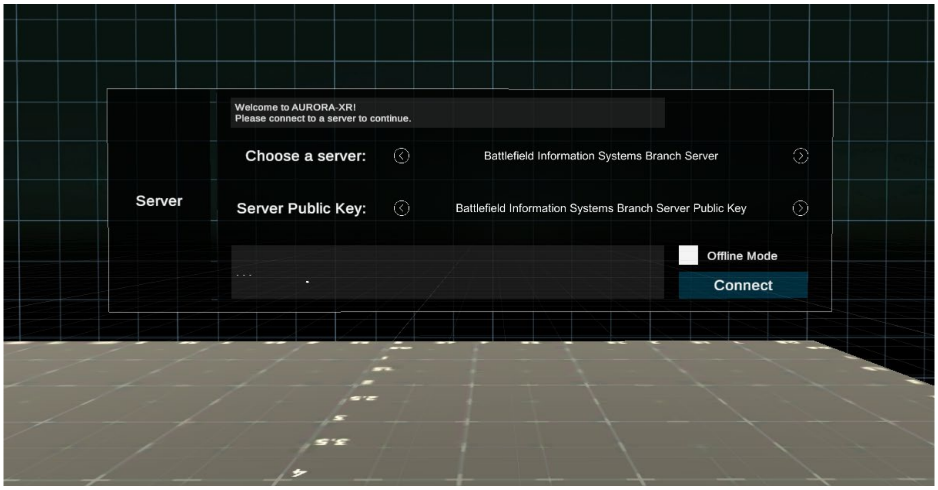

Fig. 3 Screenshot of the server selection interface

If the user is able to successfully connect to an AURORA server, they may then enter a username and password and log in to authenticate with the server. They may also select to save their username and/or password to the machine they are currently using. This interface is shown in Fig. 4.

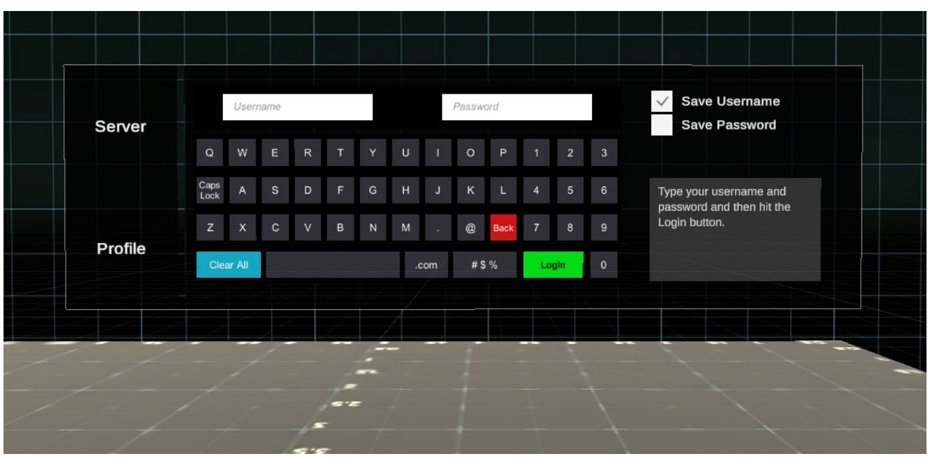

Fig. 4 Screenshot of the username and password entry interface

If authentication is successful, the user can then select a Context to join. As described in Section 3.4, a Context can be thought of as a virtual room whose purpose is different than another virtual room's purpose. Figure 5 shows the interface for Context selection. Here, the user can select either a test room or one of two Contested Urban Environment (CUE) rooms.

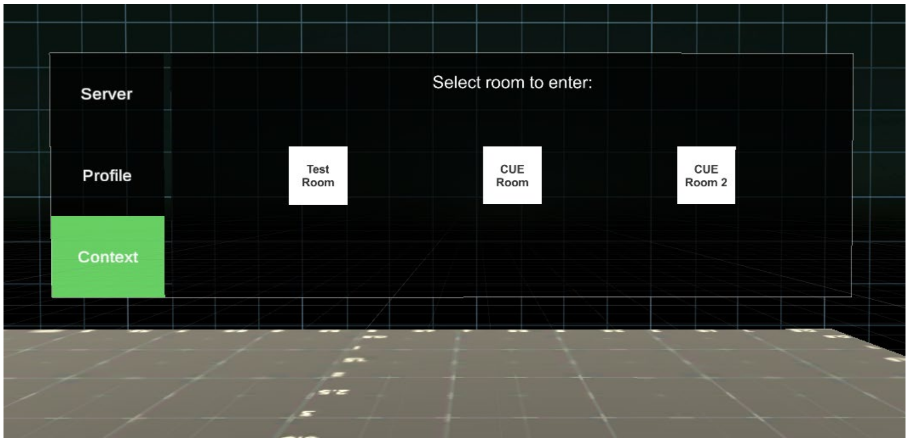

Fig. 5 Screenshot of the Context selection interface

3.5.3 AURORA-XR CUE Application (CUE-App)

The AURORA-XR CUE-App is a virtualized version of a TOC and presents an immersive way of visualizing and interacting with the COP for a dense urban battlefield scenario extending across multiple domains. The purpose of the CUE-App is to provide researchers with a testbed to study decision-making science problems at the tactical or operational levels. The existing features of the CUE-App are described in the following sections.

3.5.3.1 CUE-App Multi-User Collaborative Visualization and Tracking

The CUE-App uses AURORA-Net's transformation update system to allow synchronized visualization of the position, rotation, and scale of any virtual object inside of an AURORA-XR Context. Users are represented using three spheres that follow their head and hands in reality and map them into the virtual environment. Any object that can be moved by a user or by the system can be enabled such that its position, orientation, and scale are synchronized across all users connected to that Context.

3.5.3.2 CUE-App Synchronized Virtual Interfaces

Interfaces inside the virtual environment are used to show information about the simulated battlefield as well as information about the AURORA system. The CUE application interfaces with AURORA-Net to synchronize changes to the information in these interfaces by local user changes or by events triggered by the simulated battlefield. Currently, the CUE-App API supports synchronization of interface changes across a tabulated-style visualization structure. In other words, information may be organized as sets of top-level windows with further information organized as subsequent subtabs. Additional interface methodologies, such as scrolling, pop-ups, and so on, will require modification of the CUE-App API. An example data interface from the CUE-App is shown in Fig. 6.

Fig. 6 User interface displaying real-time information about simulated Internet of Things (IoT) devices shown as part of the CUE application inside AURORA-XR's C2 Context

3.5.3.3 CUE-App Mission Planning Tools

The CUE-App provides users with the ability to spawn in simulated Opposing Forces (OPFOR) and Blue Forces (BLUFOR; the friendly forces) at any location on the battlespace. Users are also able to place down force-colored waypoints at any position on the battlefield. These objects can all be seen and moved by any user connected to that Context. Current features include disparate views of simulated terrain through top-down cameras (Fig. 7), simulated Internet of Things (IoT) camera feeds from the environment or assets (Fig. 8), or cameras that can be positioned around the virtual room by any user (Fig. 9).

Fig. 7 Overhead 2-D view of virtual terrain shown as part of the CUE application inside AURORA-XR's C2 Context

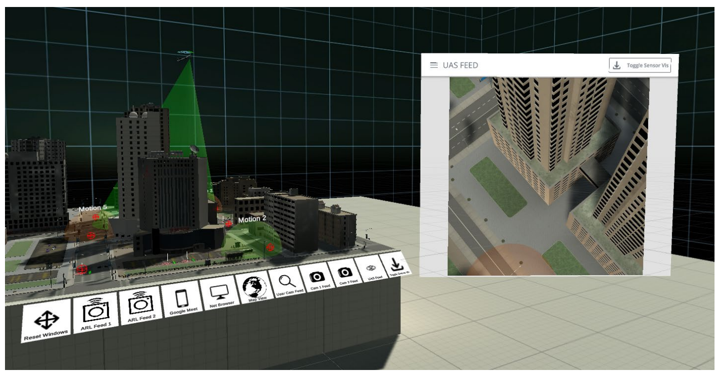

Fig. 8 Virtual camera feeds shown as part of the CUE application inside AURORA-XR's C2 Context

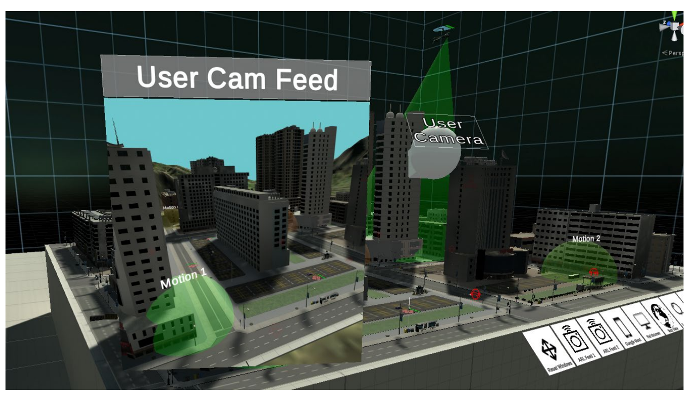

Fig. 9 Reconfigurable user camera feed shown as part of the CUE application inside AURORA-XR's C2 Context

3.5.3.4 CUE-App Simulated Sensors and Agents

The CUE-App currently supports simulation for basic patrol by OPFOR infantry units, a surveillance route by a BLUFOR air asset, and unattended ground sensors (see Fig. 10). The OPFOR units are controlled by a simple pathing algorithm in the

Unity engine and route pseudo-randomly among preset waypoints in the terrain. These waypoints can be reconfigured as desired. The BLUFOR air asset similarly follows a set path in the simulated airspace. The unattended ground sensors each contain the following properties: a unique ID, a detection range, a detection uncertainty of information (UoI) scalar, and connectivity to a centralized interface in the application that is visible to all users. The number of sensors, their location, and their UoI values are all manipulatable by the user via the Unity editor.

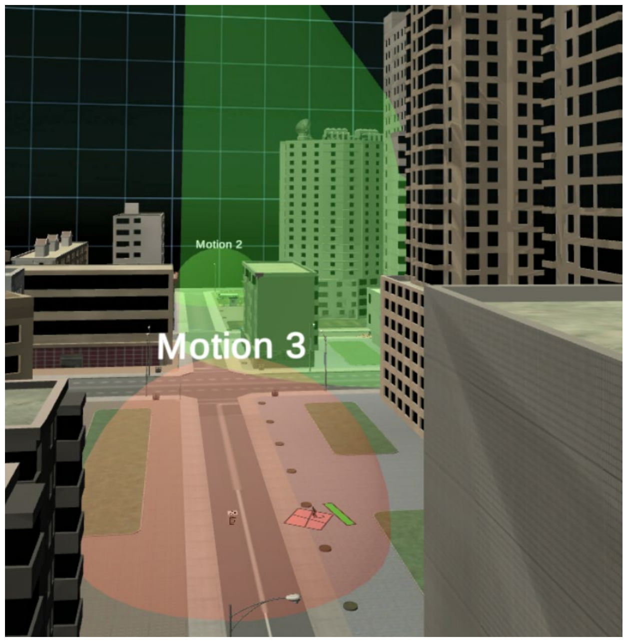

Fig. 10 Screenshot of simulated motion sensors with colors (red = high; green = low) indicating the magnitude of their uncertainty of information

3.5.3.5 CUE-App Web Browser Integration

The CUE-App features the ability to display web pages inside the virtual environment (see Fig. 11). Currently, the content of these web pages updates locally to each user's instance of the application. Interactions with the web pages are done through pointing with the right hand to emulate a mouse and right and left clicks being emulated through button presses of the palm-grip and trigger, respectively. Web pages are driven by Chromium and thus support a number of different features such as video teleconferencing services like Google Meet.

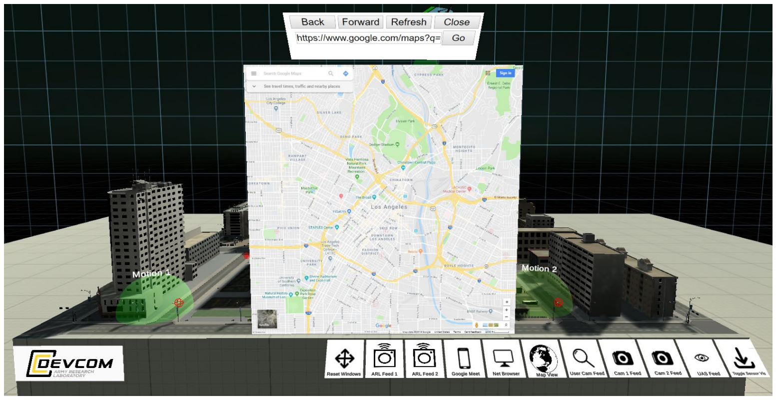

Fig. 11 Interactive web browsers shown as part of the CUE application inside AURORA-XR's C2 Context

4. Testing Results

The AURORA system has been used internally at the US Army Combat Capabilities Development Command Army Research Laboratory, at military installations, and with academic partners. The system has been tested with three concurrent users and maintained visual performance inside AURORA-XR at adequate framerates to ensure a comfortable experience for each user inside the HMD.

The current bandwidth demand is approximately 10–20 kbps per user at a high resolution of user–avatar positional tracking. Degrading the update rate of the head, left hand, and right hand of each user will change network performance. Optimizing these rates is an open research question and will benefit from automatic controllers through machine learning.

Finally, the AURORA system was taken to the National Training Center at Fort Irwin, California, in 2019 to be examined by Soldiers. We learned that, generally, younger Soldiers were extremely interested in learning to use AURORA and consider how it would affect their particular military occupational specialties, whereas more senior Soldiers preferred the systems they had trained and operated during their careers.

5. Conclusions

In conclusion, the AURORA system demonstrated its capability as an adaptive and immersive COP. However, further research and development is necessary to adapt the system to the dynamic needs of the future Warfighter. The next step is to expand the number of connected sources and services that are compatible with the AURORA ecosystem. Of particular interest is connecting AURORA to the Institute for Human Machine Cognition’s Proactive Dissemination Service, which is an extension of DisService, a pub/sub system for mobile ad-hoc networks. Finally, AURORA-XR will be expanded to enable compatibility with the Oculus Quest and Microsoft HoloLens 2.

List of Symbols, Abbreviations, and Acronyms

2-D	two-dimensional
AAF	AURORA-Application Framework
API	application programming interface
AR	augmented reality
AURORA	Accelerated User Reasoning for Operations, Research, and Analysis
BLUFOR	Blue Forces (friendly forces)
C2	command and control
COP	common operating picture
CPU	central processing unit
CUE	Contested Urban Environment
CUE-App	Contested Urban Environment Application
HMD	head-mounted display
ID	identification
IoT	Internet of Things
MDO	multidomain operations
MR	mixed reality
OPFOR	Opposing Forces
PC	personal computer
pub/sub	publish/subscribe
TOC	tactical operations center
UoI	uncertainty of information
VR	virtual reality
XR	cross reality

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