Wait, I'm tagged?! Toward AR in Project Aquaticus

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ABSTRACT

Human-robot teaming to perform complex tasks in a large environment is limited by the human's ability to make informed decisions. We aim to use augmented reality to convey critical information to the human to reduce cognitive workload and increase situational awareness. By bridging previous Project Aquaticus work to virtual reality in Unity 3D, we are creating a testbed to easily and repeatedly measure the effectiveness of augmented reality information display solutions to support competitive gameplay. We expect the human-robot teaming performance to be improved due to the increased situational awareness and reduced stress that the augmented reality data display provides.

KEYWORDS

human-robot interaction, augmented reality, virtual reality, human-robot Teaming, simulation, situational awareness

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Figure 1: Project Aquaticus: On-water view of vessels.

1 INTRODUCTION

We are investigating whether a human operator's performance in Project Aquaticus can be improved with the use of augmented reality. Project Aquaticus is an established experimental platform, as seen in Figure 1, that teams manned and unmanned marine vehicles in a competitive task. Human operators interact with their robot teammates through verbal commands. Previous work has evolved the platform from a real-world environment and 2D graphical overhead simulation to a 3D environment intended as a virtual reality experience. Details about this platform and its broader purpose are presented in the next section, but current use has allowed us to observe several limitations in human operator performance that we are striving to address with this new work.

Specifically, many operators have difficulty remembering how to issue commands with correct keywords and syntax. They also lose track of what their robot teammates should be doing to support the team effort, and have little awareness of important statuses that should drive gameplay decision-making. We believe that augmented reality can address many of these issues, if used appropriately in the context of the real-world task that situates the human operator in a motorized kayak on a water playing field. Developing the 3D simulator to experiment with augmented reality features will allow us to rapidly prototype information display options while avoiding the obvious real-world safety implications.

1.1 Project Aquaticus Gameplay

In the on-water experimental work on Aquaticus, the nominal composition of Project Aquaticus is to have two humans and two robots on the same team competing in a game of capture the flag against a similarly composed team. The robots are catamaran style autonomous surface vehicles Heron M300s from Clearpath Robotics.

The field for the game extends along the entire 160m dock and 80m into the river. Boundaries of the field are marked with floating buoys. The field is divided in half: one half of the field is the blue team's territory and the other half is the red team's territory. A team's flag, a small buoy in the team's color at a known GPS coordinate, is located approximately in the rear center of each of their territories. Teams start with all players near their respective flag.

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The flag buoys are not moved during the game–participants and robots instead grab a virtual flag (for safety to avoid collisions) and take it back to their flag zone.

The capture the flag game mechanics we have implemented are based on scoring the most points in ten minutes. To score a point, the participant must go to their opponent's side of the field, virtually grab the flag and make it back to their home flag without being tagged or going out of bounds. A buoy is located at the end of each side to indicate the original flag position. Players request flag grabs from the central game controller which is granted to them if they are (a) within the opposing team's flag zone (b) if the virtual flag is located within the flag zone, and (c) the requesting vehicle is untagged. Untagged players can defend their side of the field through the use of tags, as long as the opponent vehicle is within 10 meters. A tagged player must untag themselves by returning to their home flag zone. If a player is carrying a virtual flag and is tagged, then the flag is automatically reset to its original location.

1.2 Autonomous Teammates and Interaction

The robots are truly autonomous teammates. As described in [13], the robots leverage the MOOS-IvP marine autonomy open source project. Humans put the robots into one of several modes that are conducive to playing games of capture the flag such as attack the flag, defend the flag, cover me and follow me. These robot teammates continue to perform this task while avoiding collisions and untagging themselves until told to switch tasks. The participants interact with their teammates and simulated vehicle through an audio headset and game controller.

1.3 Problem Statement

Previous participants of the Project Aquaticus testbed have reported issues with keeping situational awareness. For example, the participant often tries to tag an opponent, but the tag request is denied. Similarly, he or she attempts to grab a flag and their flag grab request is denied. Unbeknownst to the participant, they were previously tagged and did not track that status.

Additionally, participants had a difficult time keeping track of their robot teammates' statuses. An issue that has been observed in prior tests is that a robot teammate will be tagged, and on its way to untag itself the human operator will give it a command, such as 'defend', that interrupts the untagging process. Thus, the robot will be orbiting their home flag and trying to tag opponents and have their tag requests denied. The operator's lack of awareness of the robot's tagged status is the main issue here.

Thus, we are considering how augmented reality features in Project Aquaticus might improve the human operator's ability to:

- correctly issue commands to robot teammates,
- maintain awareness of the unmanned teammates' assigned roles, relative positions, and whether they are currently tagged,
- respond appropriately with higher levels of strategic play.

2 RELATED WORK

Modern systems are combining manned vehicles with autonomous vehicles to perform tasks in challenging environments. For example, the U.S. Army has the Manned-Unmanned Teaming (MUM-T) program in which manned aircraft work with unmanned aerial systems (UAS) [22]. The U.S. Air Force's "Loyal Wingman" project is exploring manned-unmanned teaming in which an UAS and a manned aircraft work directly on missions such as air interdiction, attack on integrated air defense systems, and offensive counter air [6]. We have developed a similar manned-unmanned teaming concept in the marine domain called Project Aquaticus [9–12, 14–16, 18–20]. The marine domain is more accessible for deploying autonomous vessels (no approval is required from government agencies and vehicles can be easily stopped on the water) and yet still challenging, given the elements in the environment. Project Aquaticus has been designed to explore the interplay between human cognitive load, robot autonomy, and human-robot teammate trust. It is our goal to provide lessons learned from our platform in the marine domain to other challenging environments.

The testbed has already demonstrated a level of maturity [13] as it has collected and published real-world data for publicly available data sets at: www.aquaticus.org. Researchers have been able to leverage the datasets to extract successful tactics [21]. However, in order to run these real-world experiments, it requires a substantial amount of resources in terms of hardware and personnel and can only be performed during the ideal summer months.

Previously, we elevated the Project Aquaticus simulation from a 2D overhead view to immerse participants in a virtual reality representation leveraging the Unity 3D gaming environment and its support for virtual reality headsets [17]. Using virtual reality, participants are immersed in the capture the flag game environment similar to the on-water games in their own vehicle while communicating with teammates over voice. This gave us the capability to run experiments throughout anytime of the year and without the need for resources of on-water vehicles and personnel.

As we approach the challenge of designing and testing the new augmented reality information display features, there is much relevant work that we build upon. Endsley and Jones have composed a compelling collection of user-centered design principles and guidelines that enhance situation awareness, including a whole chapter that addresses scenarios that include unmanned vehicles [4]. Also highly influential is Azuma's 1997 work [2] surveying augmented reality in contemporaneous applications and classic challenges. More modern work by Argenta et al. [1] introduces their iLeader system, a wearable augmented reality system that provides warfighters with a 40-degree field of view mark-up of the battlefield to depict friendly force positions and enemy/target locations, as well as design guidelines in this space. A general set of Design Heuristics for AR is presented by Endsley et al. [5] that also provides a useful starting point. Collectively, we have done much work on empirically evaluating usability of interfaces that are typically used in divided-attention situations [3, 7, 8] in a way that can produce generalizable design guidelines for other efforts.

3 METHOD

The following subsections describe our approach to integrating AR features into the Unity 3D environment and testing effectiveness.

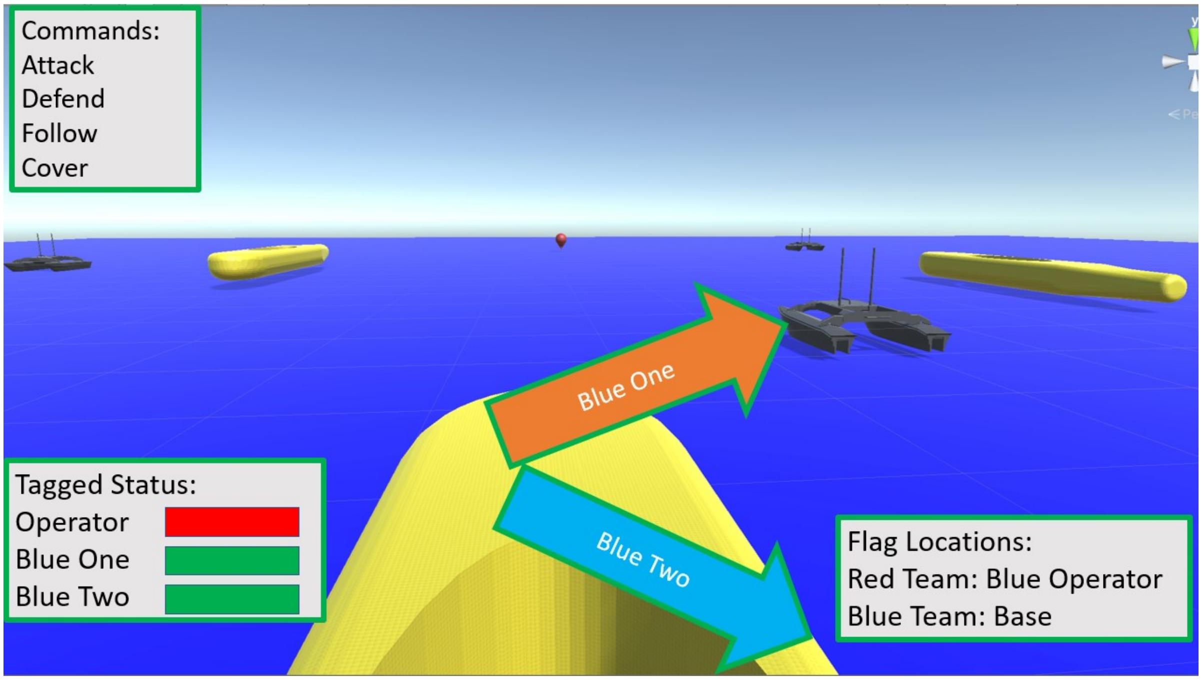

Figure 2: An augmented reality view in Unity 3D from the perspective of a Project Aquaticus participant. Augmented Reality overlays (highlighted in green) include robot teammate commands, tag status of teammates, flag locations, and directional arrows to teammate locations.

3.1 Design influence

Currently the status of the robot and the operator is conveyed over radio. Environmental factors can reduce the operator's ability to hear. Augmented reality will be used to convey information to the operator to increase the likelihood of the operator obtaining and using the information. The operator's workload will be reduced because he or she can decide when to view the data rather than having to be constantly attentive to the auditory messages. This augmented reality display will be created in virtual reality to construct a platform where tests can be done easily and consistently.

The key information that operators need and that we will display are the robot commands, tagged status of the robot, tagged status of the operator, role of the robot, location of the flag, and the location and proximity of the robot. All of the information could be displayed in text on the operator's augmented reality field of view. This is not necessarily ideal because the operator could experience information overload. The operator does not need to know the exact coordinates or distance to the robot teammate. We aim to test various information display solutions to find what amount of information is most effective and the best way to convey it. We plan to display the commands as text so the operator knows exactly what to say. The robot role will also be displayed as text so the operator can easily match them with the commands. The location of the flag will be displayed in text, stating who has the flag. The tagged status of the robot and the operator will be displayed as red or green symbols, where red indicates tagged and green indicates not tagged. The location and proximity of the robot will be displayed as an arrow with a color gradient used to indicate the magnitude of the distance. We have also considered the possibility of using an overhead mini-map graphic.

3.2 Tooling

Expanding upon our previous work of bridging Project Aquaticus to Unity 3D, we are creating the AR displays of the previously mentioned data within Unity, a mock-up can be seen in Figure 2. All of the data will be displayed as a 2D projection on the operator's field of view other than an arrow used to indicate the location to the robot teammate. The arrow will be displayed as a 3D projection onto the environment so the operator can easily tell the direction to the robot teammate. We will be using the Oculus Development Kit 2 Virtual Reality headset for visualization. Outside of virtual reality, Magic Leap's augmented reality technology could be used to display the information to the operators. We will be simulating what the operators would see if they were to use such technology in a real-world test.

Each of the new information features will be developed as a separate layer that can be easily switched on or off, perhaps dynamically by the user during the gameplay, or at least by the experimenter. This will facilitate testing progressive inclusion of features in a flexible manner that does not immediately create information overload.

The 2D graphical testbed that drives the 3D visualization already includes robust capabilities to vary gameplay simulation and perform data collection. We do not anticipate any need to modify this part of the testbed to investigate benefits of the AR features.

3.3 Experiment Preparation

Ongoing efforts involve defining the specific experimental protocol that will be used to collect user data and analyze results. However, we have some initial ideas.

There are several methods we could employ to measure the improvement of situational awareness or team efficiency. One way of measuring situational awareness is to periodically ask the participant what the status of the game is at any point in time. From their answer, we can then create a numerical score in how many things in the game state they maintain accurate awareness about.

We can also artificially create this situation by air dropping the operator into a scenario in which their robot teammate is already tagged and orbiting their home flag trying to tag opponents within reach. We will then measure the amount of time it takes for the operator to recognize the robot is tagged and instruct it to untag itself. By comparing the time it takes for the participant to resolve their robot teammate's tagged state, we can compare performance gains through the use of augmented reality features.

4 ANTICIPATED RESULTS

We expect that the human-robot teaming performance will be improved by the augmented reality display of key environment data. Producing a constantly available display of the robot commands, tagged status of the robot, tagged status of the operator, flag location, role of the robot, and the location and proximity of the robot will improve operator performance. The cognitive workload of the operators will be reduced because they will not need to be constantly attentive to the auditory messages providing the information. By improving the operator's situational awareness and reducing the workload, he or she will be able to make better informed strategic decisions.

5 FUTURE WORK

With this extension to Project Aquaticus, we envision many possible future directions, generally intended to advance understanding of how to improve a human's ability to make best possible use of robot teammates in complex tasks.

One of the immediate priorities will be to enhance the testbed by fully replacing verbal commands and auditory status updates with other modalities. We are excited to incorporate gesture and haptic interaction in a way that would complement our final decisions with regard to AR information display and be more practical in situations where silence is important. There is also much work that can be done to expand the artificial intelligence available to the robots in order to improve execution of the existing roles and others, hopefully resulting in more sophisticated strategic play. We are particularly interested in scenarios that allow the human operator to effectively direct a robot in a manner that reduces danger or stress for the human, and ultimately leads to performance improvement.

Another exciting direction is to create a similar game and experimental testbed that would make use of unmanned aerial vehicles, both human-controlled and autonomous, perhaps as an adaptation of Quidditch (of Harry Potter fame). Adapting the 2D simulator and the 3D AR/VR environment would be the obvious first step, and our experiences with observing differences between real-world and simulated experiences in Project Aquaticus would likely be important to reflect on, weighing benefits of involving actual systems. Thus, we continue investigation of human-robot teaming facilitated by AR through the use of competitive gameplay.

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