AR/VR Tutorial System for Human-Robot Teaming

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2021 IEEE 11th Annual Computing and Communication Workshop and Conference (CCWC) | 978-1-6654-1490-6/21/$31.00 ©2021 IEEE | DOI: 10.1109/CCWC51732.2021.9375845

***Abstract*—The role of human-robot teaming (HRT), or the interaction between humans and robots to complete tasks, is becoming increasingly important in the modern age. From medicine to military applications, robots have established themselves as powerful tools in the completion of human-directed objectives. Given the importance of this teaming, it is equally important that there exists a system to develop such partnerships. For this purpose we present a tutorial based on the framework of the Project Aquaticus human-robot teaming test-bed, where participants in previous experiments felt overwhelmed while working with an autonomous robot teammate. To improve and develop this participant-robot relationship, we developed a tutorial for HRT using the Unity game engine. The Project Aquaticus test-bed centers around a game of capture-the-flag played in boats on the water, where each team is equipped with two human-steered boats and two autonomous robot teammates. The tutorial is designed based on the analysis of previous literature and includes features found in other, effective training systems and tutorials. The creation of this automated tutorial system shows promise in improving the effectiveness of HRT in the context of Project Aquaticus. In the near future, the effectiveness of this tutorial system will be tested with human subjects to evaluate improvements to situational awareness and cognitive load.**

***Index Terms*–Augmented reality, human-robot teaming, simulation, training, tutorial, virtual reality.**

I. INTRODUCTION

Before explaining the purpose of this research, it is first necessary to understand Project Aquaticus and the context which our tutorial aims to operate within. In Project Aquaticus, teams of manned and unmanned marine vehicles participate in a game of capture-the-flag. Humans may steer their own vehicle and may also direct the team's unmanned vehicles through voice commands. During initial testing, participants reported having trouble maintaining situational awareness. Particularly, they spent a significant amount of time and energy trying to confirm that their robot counterpart was correctly performing a designated task. Often, the task directed to the robot did not align with what the player had in mind, and this incongruence created confusion during playtime.

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Following practical tests, Project Aquaticus was transitioned from a 2D simulation into a 3D virtual reality environment [Fig. 1], with hopes to address this issue [7]. The use of a virtual simulation also improves ease-of-use, as removing the necessity to bring boats and robots to a physical location reduces the cost of running a game of capture-the-flag and also allows for numerous repetitions within a short time frame [3].

While testing was still being conducted on the water, we encountered a clear problem: there was no standardized method of teaching new players to play the game and, more importantly, to interact with their robots. Participants were thrust into the water after a brief explanation and often could not remember all of the things they needed to do. To address participant cognitive overload, we looked towards creating a tutorial system within the virtual simulation to ensure new players understood the tools they had at their disposal, how to best interact with their robot counterparts, and how to be successful within the context of the capture-the-flag game.

The tutorial system introduced in this paper is based many of its features on lessons from effective tutorial systems in video games. While at first glance, the connection between HRT and video games may not be clear, the reality is that video games have worked towards perfecting the art of tutorials for decades. In both the Project Aquaticus simulation and in video games, a new player must learn movement controls, available tools and features, and the goal of the game.

The remainder of this paper will discuss related work in the field of HRT training, the design and implementation of our tutorial system, and paths for future research.

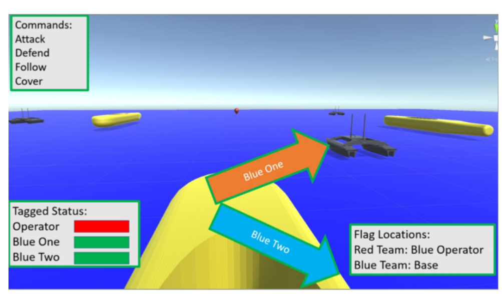

Fig. 1. Mock view from a human-steered vehicle in the Project Aquaticus AR/VR Simulation. Augmented reality information is highlighted in green and is designed to increase the player's situational awareness. [3]

II. RELATED WORK

A. HRT Training

The use of robots in completing human-directed objectives has become increasingly prevalent in the recent past. As the capability of modern machines becomes more and more complex, it has become more common to see robots used in highly technical fields and difficult environments, acting in the place of a human teammate [9]. As an example, human-robot teaming has found a role in search and rescue operations, in which robots allow their human counterparts to determine better courses of actions in obscure environments. The human operator, in this case, may direct a robot to scout out a hazardous area and report back valuable information, such as the location of individuals in a house fire, what structures are stable or collapsed, etc.

Given the important role such robots play in providing information and value to their human partners, it is understandable that a significant amount of development and training is devoted to improving the technology and systems of the robots themselves. In their research article, "Human-Robot Teaming for Search and Rescue," Nourbakhsh and his team discuss their creation of a virtually-simulated environment to train Urban Search and Rescue (USAR) robots [6]. As shown in their research, the improvement of robots regarding their architecture and capability is incredibly important in human-robot teaming. For a team to operate well, the human counterpart must be able to rely on the robot to effectively accomplish its tasks and transmit that information in a timely manner.

That being said, little research currently exists regarding the training of the teams themselves. While it is quite important that robots in these teams are highly capable, it is equally important that the human operators understand how to use them. The following sections will address the implementation of virtual reality (VR) and its role in training HRT, as well as the role tutorial systems may play in further improving this training.

B. Virtual Reality and HRT

1) Virtual Reality as a Tool: Since its creation, VR has played a valuable role as a training tool. VR is unique in that it provides a platform to practice skills without the resources such a skill may normally require (money, time, effort) [5]. A notable feature of VR is its ability to go beyond the limits of reality. Graphical user interfaces (GUIs) may be displayed on a headset to make confusing tasks more clear [Fig. 3]. Additionally, such GUIs may provide useful information for training purposes, to include mini-maps, time limits, helpful tips, and more. This feature of VR opens up several possibilities for creating better, more efficient, training systems.

2) VR in Medical Training: VR is commonly used as a training tool in the medical profession. A study published in 2002, "Virtual Reality Training Improves Operating Room Performance," took highly trained laparoscopists and, after implementing training with or without VR, tasked them to perform a laparoscopic cholecystectomy. This study found that gallbladder dissection was 29 percent faster for residents trained in VR [10]. Furthermore, "non-VR-trained residents were nine times more likely to transiently fail to make progress...and five times more likely to injure the gallbladder or burn nontarget tissue" [10]. Considering the relative limitations of VR technology at the time of this publication, some 18 years ago, it is astounding that this experiment exhibited such drastic improvement to gallbladder dissection by VR-trained residents. While this experience does not directly relate to the impact VR training may have on the effectiveness of HRT, it does show the impact VR holds on training complex skills and/or tasks.

3) Training Robot Systems: Because HRT is a complex task, as is gallbladder dissection, it is reasonable to say that implementing HRT training in VR may produce a positive impact (more effective human-robot teams). While HRT is not the same as performing surgery, the use of VR as a tool for training remains largely the same in most scenarios. Due to the lack of research in this area—training HRT in VR—a reasonable assumption is that the methods used for training other areas in VR would transfer well to this subject. A meta-analysis published in 2020 [5] explains that the value of VR (and other forms of augmented reality) lies in its ability to provide training in circumstances that exclude traditional methods. As such, VR in HRT would provide the capability to practice interaction with a robot system in any environment, with none of the cost and all of the benefit.

Given this information, the most effective method in training HRT in VR would be to reflect, as best as possible, training HRT in the physical world. This would include modeling necessary robot systems and environments in an engine such as the Unity game engine or the Unreal game engine, as well as implementing controls that closely mimic user input in the physical world. Considering the effectiveness of training robot systems in a simulated environment [6], it follows that training HRT in a similar fashion would show an improvement in the effectiveness of a human-robot team. VR may also be used to extend reality and provide better training through GUIs and tutorial systems that would otherwise not exist in a traditional environment.

C. Overview of Tutorial Systems

1) Tutorial Systems in Games: Tutorial systems provide an opportunity for a user to engage with a complicated task in more manageable pieces, allowing basic skills to build on one another as the user progresses. In the world of video games, tutorials are almost always an integral part of the user experience. Because games require the player to learn new mechanics and controls, it is almost impossible to place a player directly into a game with no guidance and expect them to perform well. While tutorial systems have been, and continue to be, implemented in other training applications, video games are a great model of how to implement tutorial systems effectively.

2) What Makes a Good Tutorial: Using video games as a guide, we can analyze the effectiveness of tutorial systems in improving player success and also examine what features and mechanics constitute a "good" tutorial. In a 2012 study, "The Impact of Tutorials on Games of Varying Complexity," researchers found that the impact of tutorial systems on player success relies heavily on the complexity of the game they are playing [1]. The study involved three games of increasing complexity, and showed a 75% increase in levels played and a 29% increase in player retention for the most complex game. While results were not as outstanding for games of lesser complexity [1], the intricacies of training HRT allows us to assume that a tutorial system would usher similar results to the study's most complex game.

Leveraging literature from other areas, using a tutorial system to train HRT should, in theory, show positive results, so the next question to answer is how to best implement this system. An article published in 2005, "Learning by Design: good video games as learning machines," states that the most effective tutorials allow the player to feel like an "active agent" rather than "passive recipients" [4]. Because video games, like HRT, are interactive, the player needs to feel invested in their decision making and actions to better learn how to play the game. Furthermore, a player must be invested in the game so they are compelled to learn its mechanics. Good games solve this by providing an immersive story to the player or by allowing the player to create their own story [1]. Additionally, good games make learning feel like a part of the experience by providing information when it is necessary, or "just in time," [11] and by offering challenges that are just frustrating enough to maintain engagement [1]. When a player starts playing a game, there is usually no reason for them to know certain mechanics right off the bat. The popular game, *Titanfall 2*, for example, does not teach its players how to perform a double-jump until they encounter an obstacle that requires that mechanic. Offering too many options too quickly is a sure-fire way to deter players from learning everything. Small chunks of information allow the player to learn progressively and to use that new information as it becomes relevant.

D. Tutorial Systems and Training HRT

Given that Project Aquaticus was transferred into a virtual reality environment, the user is now faced with a number of new mechanics to learn in addition to learning how to communicate with their robot—how to steer their own boat, how to look around in VR, etc. By breaking these tasks into more manageable pieces, the user will have a significantly higher chance of success. Given the guidelines provided by previous literature, the tutorial should mimic a progression as follows:

1) Teach user how to use VR headset by giving them things to look at/calibrate themselves with.
2) User takes control of the boat and is directed to complete tasks that require movement skills.
3) User is given a robot and a short list of basic tasks the robot may complete.
4) Flags and enemy boats are introduced. The user now needs to use previously learned skills to capture flags and defend their team flag. User is given an additional team boat.
5) User is given more advanced tasks and is now capable of using all game mechanics.
6) Tutorial ends and user is prepared to play a full game with autonomous robot teammates.

Using a tutorial that follows the steps presented above, or a similar structure, would allow a user to build on basic skills until they are capable of performing all tasks necessary for a full game of capture-the-flag with autonomous robot teammates. A requirement for each step is that the challenges presented are optimally difficult so that users learn something, but do not get frustrated or tired of playing.

III. SETUP

The following section will discuss the design and implementation of our automated tutorial system within the virtual, Project Aquaticus environment. The tutorial, in its current state, follows closely the steps outlined in the above section. The current implementation of our automated tutorial system focuses on a virtual 3D simulation, with plans to incorporate VR headset support in the near future. Thus, features which focus on VR headset implementation are not currently included within the tutorial.

At the moment, the tutorial is broken into the following, sequential phases [Fig. 2]:

1) Phase I: Movement and Controls
2) Phase II: Flag Play (Game Mechanics)
3) Phase III: Robot Interaction

These phases accomplish the same goals as the progression previously outlined, but in a more streamlined manner. Throughout our work on this study, simplicity proved essential to creating both a timely, deliverable tutorial, and a tutorial which is user-friendly.

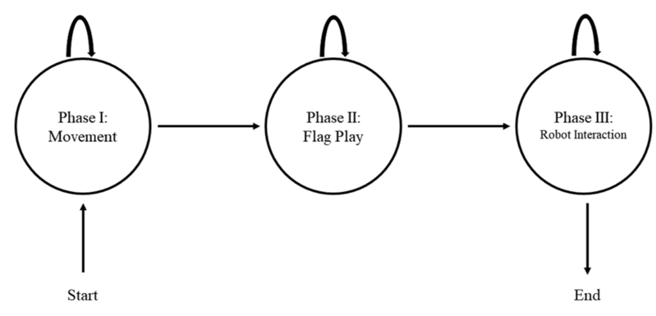

Fig. 2. Diagram of Tutorial Phases

A. PHASE I: MOVEMENT AND CONTROLS

Phase I of the tutorial familiarizes the participant with steering their personal vehicle in the virtual simulation. This is accomplished by introducing a number of "waypoints," or marked locations to travel to, and by directing the player to move to those locations. In total, the player is directed to travel to four large, red balloons placed in a clockwise pattern around the playable area of the simulation. When a player collides with a balloon, that balloon disappears and a new one is introduced at a farther point. Throughout this process, on-screen messages appear to instruct the player of their next task or to congratulate the player on completing the phase [Fig. 3].

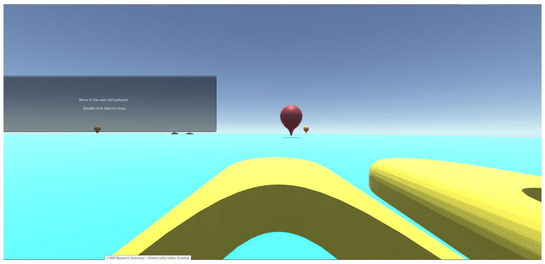

Fig. 3. Example bubble-text pop-up for tutorial instruction

B. PHASE II: FLAG PLAY

Once the player successfully navigates to all four balloons, the script which manages the tutorial triggers the transition from Phase I to Phase II. Once the player understands how to move their boat in the simulation, they are taught the importance of flag play, to include flag captures and flag defense. The implementation of Phases II and III proved the most challenging portion of our study, as communication between the Unity client and the previously created Project Aquaticus 2D simulation needed to be established before any functional code could be written.

This communication was established through an application, "pUnityShoreside," which listens to audio events in game, and sends these event messages to the Unity client for further action [Fig. 4]. These messages announce the action accomplished as well as the boat which is responsible for that action. To implement Phases II and III, we parsed through these messages to search for key actions and boats performing those actions. Specific actions performed by specific boats will prompt an event to occur, like a GUI bubble-text pop-up or the transition from Phase II to Phase III.

Once the player successfully performs a flag capture, they are directed to defend their flag by tagging an enemy boat. Once both a capture and a tag have been completed, the player transitions to the next phase of the tutorial.

Fig. 4. Diagram of Server-Client Communication

C. PHASE III: ROBOT INTERACTION

The final component of the tutorial is crucial to this study, as it teaches the player how to interact with their robot counterpart. In order to effectively introduce human participants to their robot teammates, the player is directed to interact with their robot in Phase III. Specifically, Phase III introduces four tasks which the player may direct their robot to perform—*attack*, *defend*, *follow*, and *cover*—and instructs them to successfully order their robot to perform each task once. When the robot is set to *attack* mode, it orients itself towards the opposing flag and seeks to capture it. *Defend* mode directs the robot to defend the friendly flag by steering in a circular motion around it. *Follow* mode instructs the robot to trail their human counterpart's boat, and *cover* mode instructs the robot to lead it by a few meters [8].

In addition to GUI prompts, Phase III includes on-screen video which shows a top-down shot of what each task looks like [Fig. 5]. Following the successful completion of all four tasks, a GUI pop-up congratulates the player for completing the tutorial, and the participant is ready to try their luck in a full game. Phase III is arguably the most important to this tutorial, as this phase is responsible for fostering the relationship between the human participant and the autonomous robot teammate (the ultimate goal of the tutorial). Phase III acts as a culmination of everything the player has learned from previous phases in the tutorial and introduces the final, necessary knowledge to best operate in cooperation with their robot teammate.

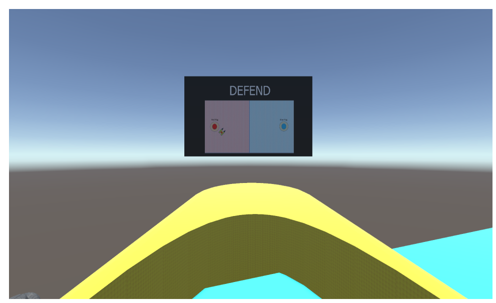

Fig. 5. Animated GUI pop-up illustrating what the autonomous robot teammate will do on execution of the desired task

IV. FUTURE RESEARCH

While significant progress has been made in this study so far, there is plenty of opportunity to continue and expand our research in the future. To start, testing must be done to determine the efficacy of this augmented and virtual reality tutorial system for training human participants. As noted in section two of this paper, it is expected that a tutorial should increase the effectiveness of HRT. With this in mind, the three measures of success will be user cognitive load, situational awareness, and team performance. In previous on-water experiments in Project Aquaticus, participants were given a quick overview of the tools necessary to be successful on the water, to include: radio operation, kayak operation, and how to communicate with their robot counterpart. It was clear that participants lacked situational awareness during testing, as many called over radio to ask for assistance or to ensure their robot was executing a desired task. It is our belief that this AR/VR HRT tutorial system will do a better job of training the participants and reduce their confusion in game when compared to previous on-water verbal training.

Future experiments will determine the effectiveness of various forms of instruction by splitting participants into three groups: verbal training, animated slide training, and training using the AR/VR tutorial presented in this paper. The participants will then play games of capture the flag in the Project Aquaticus test-bed. Using the Situation Awareness Global Assessment Technique (SAGAT) [2] as a guide, the participants will be asked questions during the game relevant to their own game state and that of their autonomous robot teammates. A measure of situational awareness will then be the number of times a participant correctly answers the game state questions versus the total number of questions. This will allow us to examine situational awareness at three levels: perception, comprehension, and projection [2].

Lastly, another route for future research involves the methods in which tutorial instructions are delivered. In its current state, the tutorial relies heavily on GUI pop-ups and other, on-screen displays to provide direction to the player. These instructions may be better delivered through audio messages, haptic (kinematic) feedback, or some combination of several delivery methods. Participants may be split into groups using each of the delivery methods described above to determine which method proves most effective for instruction.

V. CONCLUSION

In summary, HRT is important, so it is equally important to have an effective method of training it. In this study, we created a functional, automated tutorial system with hopes to train and improve HRT by ensuring participants understood the tools they had at their disposal, how to best interact with their robot counterparts, and how to be successful within the context of Project Aquaticus. The goal of this training is to decrease participant cognitive load and to increase situational awareness.

While our tutorial system is functional, this is only a stepping stone in this research. In the near future, testing should be done to analyze the effectiveness of this training on HRT in a practical setting. There are myriad opportunities for this research to grow in the future, to include VR and additional AR implementation, as well as testing the delivery of instructions within the tutorial for improved results.

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