HOCTOPUS: An Open-Source Cross-Reality tool to Augment Live-Streaming Remote Classes

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Abstract

Extended Reality (XR) has gained significant attention, offering novel pathways for learning based on the sharing of 3D content. Nevertheless, additional efforts should be spent to understand the advantages set forth by Cross-Reality (CR) scenarios, for example including Augmented Reality (AR) and Mixed Reality (MR) experiences in the context of remote live-streaming classes. In this process, a necessary step entails designing, implementing, and making educational tools available in an open-source format. To this aim, we present HOCTOPUS, a CR system designed to support live remote teaching. HOCTOPUS provides a cross-reality educational experience: an MR application for teachers and an AR mobile app for students. HOCTOPUS lets teachers visualize, manipulate, and share 3D objects in a live-streaming fashion, supporting bi-directional communication and interactions with all students. The MR component is developed for the Hololens 2, offering flexible manipulation capabilities, while the AR component runs on Android mobile devices, providing affordable interactive visualization and manipulation. The proposed tool may be used as a building block to enhance the learning process and is made available to the educational community for its use, assessment, and extension.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interactive systems and tools; Applied computing—Education Distance learning—Distance learning

1 Introduction

The advantage of adopting XR in education amounts to the possibility of learning without boundaries while having collaborative real-time interactions with different items (e.g., 2D/3D scenes, intelligent agents, chatbots, or virtual learning resources), exploiting mobile and wearable devices [5, 20, 29, 41, 51]. Moreover, XR has proven to facilitate engagement and learning-by-doing, also in a collaborative fashion [16]. Features such as advanced 3D model visualization, manipulation, and physical object augmentations, are often exploited to encourage and increase learning motivation and efficacy [5,12,19,21,25,30,32,36,39,51]. Educators of specific sectors such as Architecture, Engineering, Cultural Heritage, and Medical sciences are applying these paradigms to seek improvements in their learning paths [21, 39, 51].

Within the XR umbrella, VR and AR/MR exhibit different opportunities, considering that the former allows placing a student in fully digital spaces whereas the latter supports an entanglement of physical and virtual objects [9, 12, 19, 21, 32, 36, 38–40, 51]. AR/MR technologies appear particularly interesting considering that: (a) it is possible to blend existing educational tools to provide new narratives in augmented environments, (b) may in principle require smaller investments in 3D content creation, and, (c) may provide a visual bridge between an object under study and its digital twin [22]. Despite such promising aspects, only a few works focused on studying the possible advantages and effects of AR/MR experiences to empower remote classroom teachings, and even less considered live streaming classes [3, 5, 28, 32, 33, 49]. In most of the cited projects, one of the common findings is that visualizing and manipulating 3D objects may increase learning effectiveness while also expanding student engagement [5, 32]. It is worth noticing that the majority of such works exploited the Microsoft Hololens 2 MR device as this was considered the best headset on the market [23, 27, 28, 31, 49]. Moreover, none of the aforementioned works publicly provided their implementations in an open-source format. Finally, to the best of our knowledge, none adopted a Cross-Reality perspective (CR) to support interactive live-streaming remote classes [15, 34, 35]. However, CR could be of particular interest in such an application context, considering that the teacher and the students have different needs and roles while participating in a live-streaming remote class. The teacher should use a performing device that provides high manipulation flexibility for virtual objects while presenting the lecture material, while the students could use a lightweight and affordable device that supports a simpler manipulation and interaction system (asking questions supported by 3D object manipulation, as an example) [10]. Following such a perspective, we here introduce an open-source CR platform [34, 35], comprising AR and MR components, to support live remote educational paths, named "HOlolens remote Class Teaching with peer-tO-Peer objects Unity Synchronization" (HOCTOPUS).

HOCTOPUS [1] provides a simple interface for teachers and students to visualize, manipulate and share 3D objects in live streaming. In particular, HOCTOPUS is a CR platform comprising, for teachers, an MR streaming experience that supports the sharing and manipulation of a 3D model and, for students, an AR interface showing the streamed 3D object, as manipulated by the teacher. Students can also interact with the object and ask questions [14]. The MR application has been developed for the Hololens 2 [27] and the AR one for Android-based mobile devices. Overall, the proposed system has the potential to be applied and extended to a large number of lectures supported by the sharing of 3D objects. In addition, the platform supports two-way interactions, as students can collaboratively manipulate a 3D model along with the teacher. Considering that HOCTOPUS combines MR and AR clients, it could be extended by integrating spatial anchors, and in general, supporting classes where the surrounding spatial context is relevant (i.e., engineering, design,

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[1] The implementation of the system is available at https://github.com/VARLAB-Unibo/HOCTOPUS.

architecture).

The choice of implementing the MR teacher application for Hololens 2 and the AR student one for mobile devices obeys the following rationale, inspired by CR frameworks [15, 34, 35]. The Hololens 2 is costly but provides more manipulation flexibility and freedom of movement, unleashing all the spatial features that this device offers (e.g., spatial mapping, hand tracking, automatic element positions, and tested UI elements). On the other side, the mobile application provides a lightweight and spatial-aware visualization of the actual state of the 3D objects, with an effective but less flexible manipulation system [7]. However, the majority of students nowadays possess a mobile device, allowing students to join the remote stream class at no additional cost [42]. In essence, the contributions of this work amount to a CR system comprising: (i) A novel MR application platform for the Hololens 2 [27], that allows educators to teach classes while streaming one or more 3D models manipulations; (ii) A novel mobile AR application that allows students to connect to a remote class and ask questions, interactively, about the streamed object components.

The rest of the paper is organized as follows. Section 2 presents a review of the state-of-the-art works that fall closest to this work. In Section 3, a description of the HOCTOPUS system architecture and the description of its main functionalities both for the MR and the AR client applications is reported. Finally, Section 4 describes the limitations of our work and features possible future extensions of the proposed tool.

2 Related Works

The integration of XR technologies, in particular AR and MR, in education has gained significant attention in recent years, providing different and effective applications for teaching concepts and skills in different fields of study [1, 4, 17, 20, 47, 50, 51].

In educational contexts, AR and MR have the advantage of supporting digital objects blend with the surrounding objects and environment [1, 8, 17, 51]. In addition, features such as advanced 3D model visualization, manipulation, and real object augmentation, are often put to good use to encourage and increase teaching and learning efficacy [5, 12, 19, 21]. A good amount of AR and MR systems have hence been designed for professional training and teaching in medical procedures, design buildings, and different industrial tasks (e.g., assembly pipelines, object maintenance) [5, 6, 12, 19, 21, 31, 39, 43, 51]. As an example, [6] provided an interactive AR virtual visit to a construction site. Using an AR device and a finger motion tracker, students were allowed to augment the scene with relevant information while interacting with predefined objects, improving the general learning experience. As an additional example, in [43], its authors exploited an MR device to visualize and study limb anatomy. When compared to traditional educational pathways, while the final level of competence was comparable, less time was required using MR, implying that MR may be equally effective but more efficient for teaching musculoskeletal anatomy.

Despite the bloom and successful AR and MR applications in education, just a few works exploited such paradigms for live remote classes [3, 28, 32, 36]. In fact, to the best of our knowledge, only [3, 28, 32, 36] studied the possible effects of such paradigms in such contexts. It is worth noticing that all such works exploited the Microsoft Hololens 2 as the target live-remote MR streaming device [27]. Authors of [3, 28, 36] proposed an Hololens 2-based application to deliver live-streamed remote in-hospital-teaching sessions. A teacher could use a live streaming MR application to share her/his view while furnishing the chance of overlaying annotated pictures related to the patient status, following an approach similar to [11, 40]. In both works, video communications relied on Microsoft Teams software. The authors proved the effectiveness of both the chosen device and the teaching method. However, no way to load, manipulate and stream 3D objects with interactive features both for the teacher and the students was provided. Differently from the aforementioned works, [32] exploited the Hololens 2 to stream 3D video camera frames from one place to another (in the study, from Finland to Namibia schools), to let remote students have a telepresence experience with live rendered holograms. Although promising, this work lacked hologram interactions support.

Finally, to the best of our knowledge, no previous works have explored a CR perspective, combining MR and AR solutions for interactive live remote class teaching, including 3D object synchronization and active participation for students, as proposed in this work. Moreover, none of them provided their implementations publicly in an open-source format.

3 HOCTOPUS: HOlolens remote Class Teaching with peer-tO-Peer objects Unity Synchronization

As described in Section 1, HOCTOPUS provides two different XR applications, developed with the Unity Editor and Game Engine (version 2021.3.x): the MR one for the teachers and the AR one for the students. In this Section, we report the system architecture along with all the tools used to implement our solution. The MR Teacher application was developed for the Hololens 2 [27], using the Mixed Reality Toolkit (MRTK) [26] framework while the AR student interface was implemented for mobile devices (in particular, Android-based ones) through the AR Foundation and the Google ARCore frameworks [13, 44]. Such choice was mainly aimed at providing a teacher with the opportunity to freely manipulating a 3D object using a simple interaction system based on natural interactions (i.e., hand gestures or voice commands). Also, students should possess a learning interface that allows sufficient flexibility level in object manipulation, but at a reasonable price. Considering the cost of an Hololens 2 device [27] and that most students nowadays possess a smartphone [42], we decided to develop the AR student client application for mobile devices.

HOCTOPUS was implemented as a special case of the client-server architecture: the MR and AR systems, are considered peers with different roles (MR is the "server" and the AR is the "client"), and all the data flowing between them is managed and delivered by an intermediate Relay server (RS). Relay servers are employed in multiplayer XR experiences that mimic a client-server schema: one application (called the host) acts as a "server" and all the others (called connecting clients) as the "clients". The RS allows communications between the server the clients, allowing the server to broadcast information to all the connected clients. This perfectly matches our XR Remote Class Education use case: the host role is covered by the MR teacher application, while the AR students correspond to the connecting clients. Figure 1 depicts the structure of a typical HOCTOPUS remote class session: the teacher hosts the remote class with the Hololens 2 while students connect to it with their AR smartphone applications, through the RS.

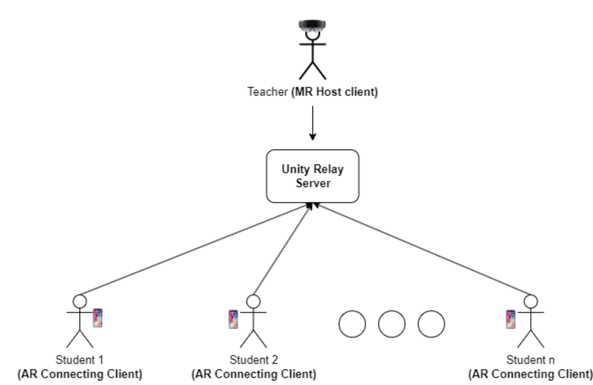


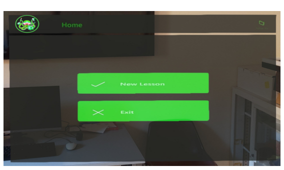
Figure 1: System architecture overview.

For our implementation, we used the Unity Relay Service (UniRS) which provides a simple and effective way to deploy an RS and to establish a secure multi-party peer-to-peer connection without requiring the creation of a custom game server [46]. At the same time, we adopted Netcode for GameObjects (NGO) which allows to transmit GameObjects data to multiple players simultaneously during networking sessions. NGO can be used along with the UniRS to send updates regarding the properties of one or multiple virtual 3D Objects [45]. In particular, we exploited NGO primitives to synchronize the state of the 3D model manipulated by the teacher to all the connected mobile phone clients. As a final note, we considered only *.fbx* 3D model files [24].

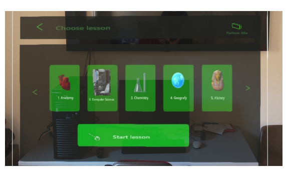
3.1 HOCTOPUS: Mixed Reality Client on the Hololens 2

For the particular use case of live-streaming classes, where a teacher may require a high level of manipulation flexibility and freedom of movement, we opted for an MR application running on the Hololens 2 [32]. User Interactions were implemented with the hand-interaction system provided by the MRTK [26]. Specifically, we sought to provide the following features: (a) 3D model loading, (b) picking one object, (c) starting the remote class, (d) streaming the manipulations made with the object, and (d) management of the connected students. Following the architecture provided in Section 3 the MR Teacher app exploits the UniRS by hosting the remote class session that the connecting clients will join (this aspect is used in features (c),(d), and (e)).

Start/End a Remote class Once a teacher runs the MR application on the Hololens 2, a simple menu is spawned, including two virtual buttons that allow to exit the application or start a new remote class (check Figure 2a). By clicking the "New Class" button, the system spawns a new Menu containing all the classes the teachers has defined (Figure 2b). Here, a data-driven approach was adopted: virtual menu elements can be dynamically generated based on existing data. In practice, a simple combination of a multimedia 3D model database along with a SQL (or even a NOSQL) database registering data for the lesson, could be used to organize, fetch and visualize the info about all the classes and the objects a teacher wants to use in HOCTOPUS. In our implementation, we just provide this approach by mocking-up five different classes.



(a) Starting Menu.



(b) Pick a class Menu.

Figure 2: MR interface for Starting and Pick Object Menus.

When a teacher picks the class s/he wants to teach, communication with the UniRS starts. The MR "Host" application sends a request to the Relay Allocation Service, which, based on the information received from the Host, spawns a RS where the network session for the live remote class will be hosted. Once the RS is allocated, the Host requests a join code. This special code will be used by the connecting clients to join the same remote class.

The Host MR application is also responsible for managing and updating the information about the 3D object state of the class to all the connected clients. To carry out this task, the MR system spawns an NGO process that synchronizes the state of the class objects by broadcasting it to all the connected clients, exploiting the UniRS. Once the NGO process was spawned, the user is asked to watch the floor to place the spawned 3D object in a suitable position. At any moment, the MR host could close the remote class session by sending a disconnection signal to the UniRS. This action will disconnect all the connected clients from the session and will shut down the allocated RS.

In-Class activities: 3D object Manipulation and Connected Students Management Once a teacher started the class, s/he has the chance to manipulate the spawned 3D Object and manage the connected students. To ease the interaction for those different features, we designed a Hand-Menu, which is always accessible, allowing the teacher to not get distracted by searching the Menu in the surrounding space [48]. In practice, we exploit the Hand-Tracking system provided by the MRTK to spawn in the user's right hand, a general menu, that is used to enable the aforementioned features. Figure 3 depicts the user's right-hand menu. It is worth noticing that, each of the functionalities provided in such a menu, will spawn new and different menus, allowing to concretely actuate those features. As visually reported in Figure 3, the right-hand menu provides the chance to: (a) visualize the connected student list, (b) manipulate the 3D model, (c) reset the position of the 3D model, and finally, (d) substitute the 3D model with another one.

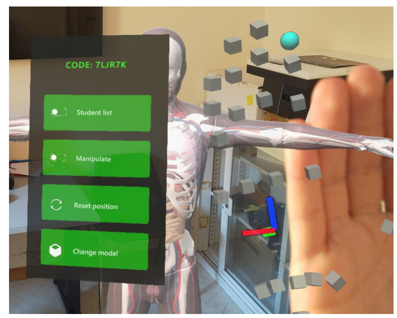
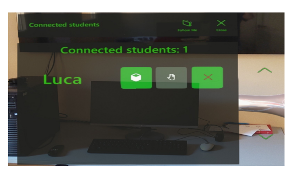
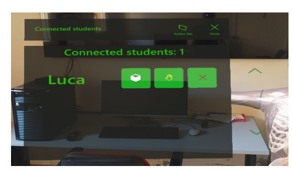


Figure 3: User's Right Hand Menu spawned in front of the 3D model during a remote class stream.

When the user interacts with the "Students list" button, a novel menu appears, showing the list of the connected clients. Per each client, the teacher can give the student permission to remotely manipulate the 3D model for the question (further described in Section 3.2), accept a student's question, or remove s/he from the remote class session (Figure 4). It is worth noticing that when one of the students raises their hands to ask a question, the system will pop up a notification with a virtual element in the teacher's view.



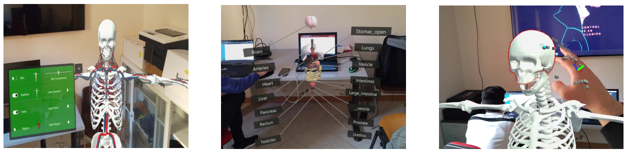
(a) Connected Students list Menu.



(b) One student raised her/his hand.

Figure 4: MR interface for Student List Menu.

The "Manipulate" button enables all the 3D object manipulation features. In particular, the teacher could move and rotate the object, show and hide the object components and correlated labels, and outline any visible components. In Figure 5 we report a graphical representation of all the aforementioned features except for the classical model roto-translations. We here recall that all of these manipulations are streamed to all the connected clients. The "Reset position" button allows to reset the model position to its original state. Finally, the "Change Model" lets the teacher change the utilized object.



(a) Teacher hides two components from the 3D object. (b) Teacher shows the labels of selected 3D object components. (c) Teacher outlines one component of the 3D Object.

Figure 5: MR interface for 3D Object manipulation.

3.2 HOCTOPUS: Augmented Reality Client on smartphones

In contrast to the MR teacher application, the AR student one was designed for smartphones (in particular, Android-based ones). The student application of an Object-centric Remote Class Platform like ours should provide the following features: (a) visualizing the current state of 3D models streamed by the teacher, (b) asking questions related to the object, (c) manipulating the object while asking a question to ease the communication between teacher and student. The student AR app exploits the UniRS to connect to the hosted class as connected clients. All the AR-related features were developed with AR Foundation and AR core [13,44] and the system can be used with any Android smartphone with a version greater or equal to 8.0 (Oreo) [2].

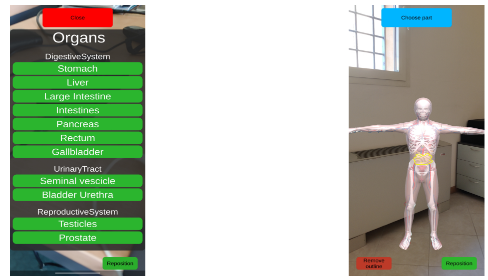
Join Remote Class and Visualize 3D Object Manipulations Once a student runs the AR application on a smartphone, the application lets her/him join a hosted remote class by typing the secret code generated by the host app. After that, the student is able to visualize all the manipulations made by the teacher in the MR app, communicating with the NGO process hosted by the MR app in the UniRS. In practice, the AR app continuously communicates with the UniRS to fetch updates regarding the 3D network object streamed by the teacher and locally update the current state of the object. Figure 6a visually depicts the AR app views to join a class while Figure 6b shows the view immediately after joining it.

(a) Mobile app Login Form. (b) View after joining the remote class.

Figure 6: AR mobile interface Remote class Login and Stream for students.

Ask a Question with 3D object Manipulation While following the remote lesson, a student has the chance to "raise her/his hand" to ask a question. A notification will immediately be sent to the MR app and the teacher has the opportunity to allow the question or reject it. While the student is expressing her/his question, the system supports its clarification by letting s/he outline, with touch interaction or selection through a hierarchical component list, one of the components of the 3D object streamed. Information about the object outlined by the student is continuously synchronized with UniRS and the NGO process, which will reflect the outline in the teacher's view in the MR application.

In this interaction modality, the system provides two different ways of selecting a particular component while asking a question (i.e., touch and list) considering that the display interaction with AR elements in mobile devices is often harsh concerning very complex elements. Moreover, some object components could be "hidden", because other components overlay them (e.g., in the human body object structure, the skeleton hides different organs). This particular feature encourages teacher-student interaction in remote classes, which was demonstrated to be a key factor in student engagement in online classes [18,37]. Figure 7 reports the student's interaction views for the object component selection in the AR app.



(a) Component selection list. (b) Outline Selection.

Figure 7: AR mobile interface for Student Question.

4 Conclusions

We here introduced HOCTOPUS, a CR platform that exploits both MR and AR aiming to enhance live remote classroom experiences by providing educators and students with a novel way to stream and interact with 3D objects in real-time. In particular, the MR application, developed for the Hololens 2, lets a teacher host a live-stream remote class, where s/he can manipulate in several ways a well-defined 3D model mirroring all of these manipulations to all the connected students. The AR application, developed for mobile devices, provides a more accessible and easy-to-use system to follow the class hosted by a teacher while letting the students make questions, supported by a network object outline system.

It is worth noticing that the here proposed system presents several limits. Firstly, our system did not provide a grouping system to implement an "exploration feature" that let students visualize and join any hosted remote class in a certain group domain through an authentication system (such as schools or e-learning platforms). Secondly, our system does not include a method for teachers and students to annotate the considered 3D object with multimedia data (e.g., texts, audio, images) which could be particularly effective to take customized "notes" as in regular classes. In future works, we plan to integrate these features and carry out an experimental user study, with both teachers and students, to validate the proposed tool.

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