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Augmented Reality Platform to foster Collaborative Manipulation of 3D virtual objects: A Prototype

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Abstract — **This paper presents a prototype platform that enables co-located collaboration through manipulation of virtual objects using Augmented Reality (AR) interfaces. The goal is to allow multiple users to collaborate in shared activities, taking advantage of recent advances in AR interaction methods and hardware. As case study, we focus in three main modules: 1- Assembly of a virtual race car; 2- Collaborative construction of a virtual racetrack; 3- Collaborative competition using the virtual content created using previous modules. We employed different manipulation techniques depending on the AR device being used, such as touch gestures, device movement and controllers. The communication architecture developed for the platform allows synchronous manipulation of virtual objects among different cross-platform devices.**

Keywords — Collaborative Augmented Reality, Co-located Collaboration, Manipulation, Interaction.

I. INTRODUCTION

Augmented reality (AR) provides a way to enhance our environment with computer-generated information, that can take several forms, ranging from virtual objects to metadata depicting the user surroundings [1]. Nowadays, AR can be found in various practical day-to-day areas of application, such as museums, tourism, advertising, education, industry, among others [2][3][4]. Even though, AR shows great promise and is commonly used to enhance a single user perception of reality, one of the areas where it can be most useful is collaborative solutions [5][6][7]. Collaborative AR can be described as an AR solution where "multiple users share the same augmented environment locally or remotely [8] and which enables knowledge transfer between different users [9]". It has the potential to support effective knowledge transfer between multiple collaborators, allowing them to interact with each other in a context-sensitive manner. Nevertheless, Collaborative AR research is still in its infancy [6].

Nowadays, thanks to the proliferation of mobile devices, users can access AR through a personal perspective or share and interact with other users using techniques not possible with traditional technology [6]. Being able to collaborate in the same physical environment through AR requires an interface able to synchronize the result of users' actions. Current research in 3D object manipulation has been mainly focused on single user interaction [10]. The most popular input method is touch-based gestures, which are mapped from a 2D space (screen) to 3D world transformations [11]. Despite this fact, other methods also exist [12]. Henrysson et al. [13] proposed a natural way to move and rotate virtual objects by leveraging the real movements of the user in 3D space, where the object's transformations changed while the user moved the device. Grandi et al. [14] proposed a handheld-based user interface for collaborative object manipulation for shared displays. Their results showed that accuracy increases as a function of group size and work division strategy. Zaman et al. [15] explored collaborative user experience in the design of a spatial layout using head-mounted VR displays and hand tracking devices. They argue that a shared-view virtual environment allows collaborative articulation of spatial design problems and improves communication between designers regarding spatial interaction and communication. Besides the works presented, we can argue that manipulation using new AR/VR hardware like HMDs represents an opportunity worth exploring.

In this paper, we present the early steps towards a platform that enables co-located collaboration through manipulation of virtual objects using AR interfaces. The platform provides different types of interaction between multiple users through different cross-platform devices. The goal is to create a platform that may be useful to promote collaboration in a co-located shared environment. As an example of collaborative scenario, we focus on a case study with three main modules: 1- Assembly of a virtual race car; 2- Collaborative construction of a virtual race track; 3- Collaborative competition using the virtual content created using previous modules. To display and interact with the virtual content we used two types of devices: handheld (mobile devices) and HMDs able to provide haptic feedback, as this is an important factor when applied to real-world tasks such as assembly-related tasks [16]. In addition, to enable the creation of the race car, we explored three different interaction methods: touch gestures, device movement and the controllers associated with a HMD. The communication architecture supporting different AR devices is presented, as well as some challenges identified during the design and development of the platform. Finally, concluding remarks and ideas for future work are drawn.

II. Platform for Manipulation of 3D virtual objects

In this section we describe a platform for co-located collaborative interaction between two or more users, allowing manipulation of virtual objects collaboratively in several scenarios using AR.

A. Case Study – CARS

As case study we used a scenario that encompasses several modules, focusing on different aspects: 1- Assembly of a virtual race car, using virtual building blocks; 2- Collaborative construction of a virtual racetrack; 3- Collaborative competition in a shared environment using the virtual content previously created. For each one of these, we employed different interaction and manipulation techniques depending on the AR device being used.

The **first module** focusses mainly on 3D object manipulation where the user builds a virtual car using building blocks. This task can be performed using three types of virtual object manipulation: touch gestures, device movement and the controllers associated with a HMD.

- **Touch gestures:** users select an object by tapping into the object position in the mobile device screen. The platform provides feedback by changing its color to green, allowing moving it around the environment by dragging the finger in the screen. Additional buttons exist to control the rotation and height of the selected piece, as shown in Figure 1.
- **Device movement:** uses touch to select virtual objects. Then, the piece color changes, and the device movement is used to control its pose in the virtual environment, being the device movement replicated by the piece, as depicted in Figure 2.
- **Controllers:** uses the HTC Vive Pro HMD and its' controllers to manipulate virtual objects, by pressing and holding the controller trigger respectively, as shown in Figure 3.

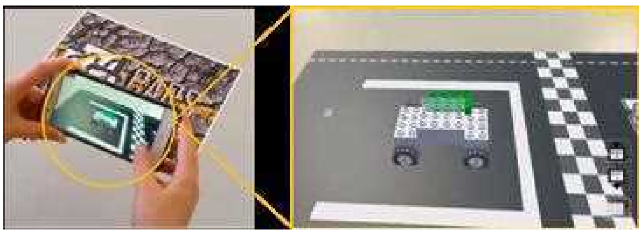

Figure 1. Module 1 - using Touch gesture manipulation.

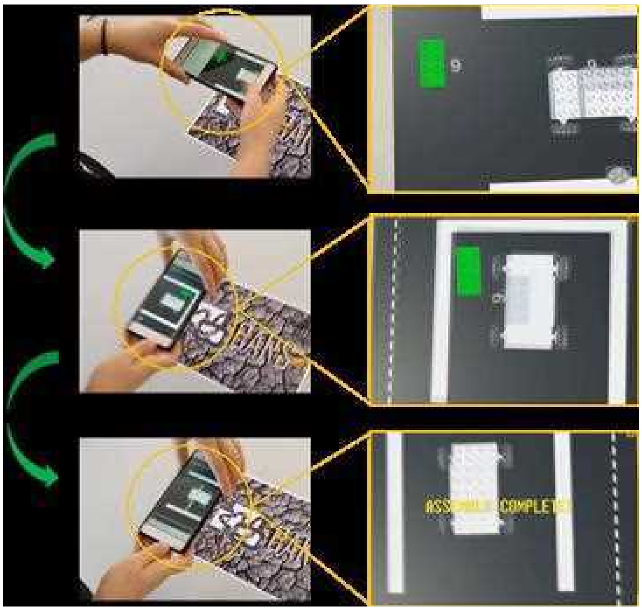

Figure 2. Module 1 - using the device movement to manipulate virtual objects.

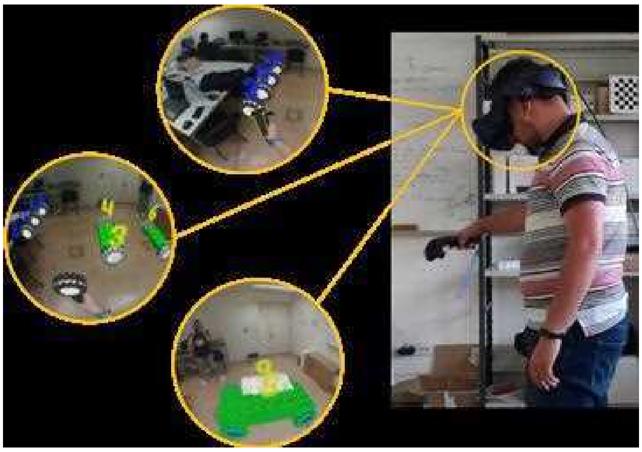

Figure 3. Module 1 - using the HMD Controllers to select (left) and manipulate a virtual tire (center) and a LEGO block (right).

For all manipulation types, the color changes to indicate a correct placement upon the user placing a specific virtual piece near its desired position and orientation. To fit the virtual object to the desired pose, the rotation and translation metrics were empirically estimated. We set the empirically thresholds of a successful match to be 8 degrees for rotation and 0.01 meters for translation.

The **second module** focus on building a racetrack through virtual object manipulation within a co-located collaborative environment. The platform features different block sections to be used during the assembly of a racetrack: a straight road, a curve and a road bump section. Users can take turns in creating the racetrack or placing several sections at once during their turn (Figure 4). Moreover, users can edit parts of the track placed by other users in the shared environment. In addition, race tracks can be saved for later, allowing to skip the first two functionalities in future competitions.

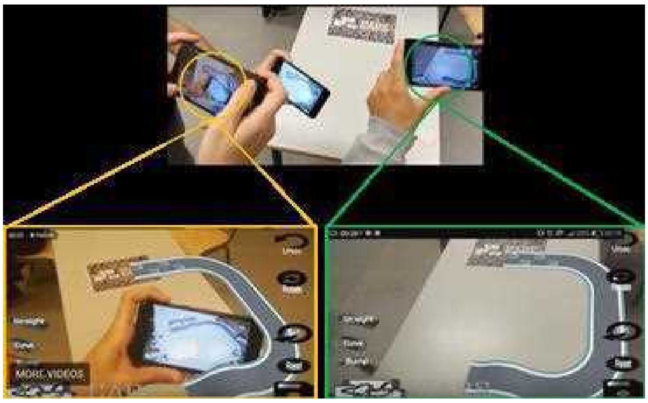

Figure 4. Module 2 - Collaborative assembly of a race track using mobile devices in a co-located scenario.

The **third module** focus on competing against other players using the race cars assembled in the first module and the racetrack designed in the second module (Figure 5). The platform allows users to join or withdraw from the race at any time. While using a mobile device the user can control the car trajectory using a virtual joystick and two buttons, one to accelerate and another to brake and move backwards (Figure 5). Besides, the player can also use the HTC Vive Pro controllers to manipulate the virtual car. The controller trigger is mapped as the acceleration pedal, while the car direction is controlled using the controller rotation (Figure 6).

Figure 5. Module 3 - Co-located competition with multiple users.

B. *Architecture*

The platform architecture focus on synchronous communication between devices, where two or more users can synchronously collaborate in a shared environment, manipulating virtual objects using different AR devices. To support this type of collaborative environment, we used a communication mechanism based on a Server-Client approach as depicted in Figure 7, focusing on simplicity and scalability.

Figure 6. Module 3 – User participating in a co-located competition, using the HMD controller to drive the car.

The platform exchange messages (based on specific events) between devices to trigger updates on the interfaces of all devices, as long as they are connected to the same wireless network. The server is responsible for managing multiple user connections, creating the necessary communication channels and assuring that all changes in the platform are replicated through all devices. The server also contains a local storage, with the current state of all virtual objects. According to the device used, different interaction possibilities and user interfaces are available. Nevertheless, the communication process remains the same to all devices, allowing the addition of new devices without being limited to specific technologies. The platform was developed using the Unity 3D game engine, combined with specific SDKs for the different devices used. To place the virtual content in the real-world environment, we used the Vuforia library to recognize predefined markers.

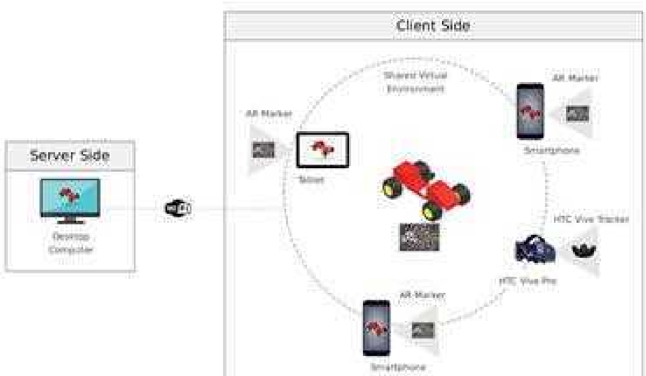

Figure 7 – Platform architecture for collaborative manipulation of 3D virtual objects using AR in different cross platform devices.

III. Challenges and Opportunities

During the design and development of the platform we identified several challenges and opportunities associated to the creation of shared co-located environments for multi-user collaboration. These were also identified by several teachers and students, during preliminary presentations and tests with initial prototypes at our university.

Our main goal was to address synchronous co-located collaboration between multiple users through AR. Yet, current development technologies offer limited information regarding this, being mostly focused on the implementation of solutions for single users. Therefore, it was necessary to understand how to address this limitation. Our architecture (Figure 7) reflects our solution, taking advantage of simple and available mechanisms to construct the AR environment in each device, and broadcast each new state to all users. It was also challenging to understand how to implement the concept of ownership, in order to guarantee authority over the respective objects. For example, for the racetrack construction we had to recognize the existence of different sections before placing new ones properly (aligned), that could be owned by different users.

Regarding 3D object manipulation, we implemented three different methods based on the current literature (Section 2). Device movement where the user moves the device to control the transformations of virtual objects was the more demanding type of interaction to implement and to teach users how to use, due to its particularity of having to move the device, which some users believe not to be natural/intuitive. Yet, some users suggested a hybrid mechanism, combining this method with the touch gestures could be the most useful means to manipulate virtual content.

Last, we explored the new addition to the HMD market, the HTC Vive Pro, promising AR capabilities, which could be very interesting for collaborative scenarios. Our goal was to take advantage of the wireless controllers to provide a more natural manipulation of virtual objects when compared to handheld-based devices. Although it is a robust VR HMD, the cameras resolution remains very limited, displaying a blurred representation of the real world (Figure 6), which in turns impacts the users immersive experience.

IV. Concluding Remarks and Future Work

In this paper, we presented a platform to support co-located collaborative AR using different interaction and manipulation methods. We addressed the unique challenges of Collaborative AR, allowing multiple users to interact, manipulate and collaborate in the creation of a race car, a racetrack and compete against each other in the same physical environment. Even though our case study is very specific, we believe the manipulation and interaction methods are modular and agnostic enough to be used in other application scenarios as museums, education, crisis management, serious games, design, among others.

Future development will focus on conducting formal user studies to understand which is the best manipulation method (from the ones we presented) in collaborative scenarios. Also, continue to develop the platform in order to support remote interaction, allowing remote users to participate, regardless of their localization. Finally, explore how information can be exchanged without interfering with the users' task, a common problem in AR-based solutions, which is even more relevant in collaborative scenarios.

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