CrowdAR Table - An AR Table for Interactive Crowd Simulation

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***Abstract*—In this paper we describe a prototype implementation of an augmented reality (AR) system for accessing and interacting with crowd simulation software. We identify a target audience and tasks (access to the software in a science museum) motivate the choice of AR system (an interactive table complemented with handheld AR via smartphones) and describe its implementation. Our system has been realized in a prototypical implementation verifying its feasibility and potential. Detailed user testing will be part of our future work.**

***Index Terms*—Crowd simulation, augmented reality, interfaces**

I. Introduction

Crowd simulation software can be used in various contexts, such as finding out how to improve crowd flow in public places [1], but also for educational purposes, such as teaching people about potential crowd-related problems in cities or at special events. Likewise, examples exist where such software has been used to teach scientific principles about running simulations to answer research questions [2]. In [3], we categorized such use cases and analyzed them according to their needs and user requirements. We identified that immersive environments with by different virtual (VR) and augmented reality (AR) implementations have great potential in this context. AR appeared particularly suited for educational purposes where expected users include the general public and thus vary significantly. Based our analysis, we describe a particular use case in this paper: AR interfaces for access to crowd simulation software in a museum. We motivate our design choices and report on the actual implementation and summarize the current prototype along with its interaction concepts. A thorough evaluation of the system with actual end users is part of our future work. The contributions of this paper include:

- A motivation of design requirements for a relevant use case of AR interaction in context of crowd simulation.
- A system design that is based on these requirements, implemented, and verified for its feasibility. It includes a state-of-the-art implementation of an "AR table" as well as a new interaction concept combining this table with handheld AR.

II. Crowd Simulation in a Museum Context

The goal of our research is to provide a museum in Utrecht that focuses on scientific exhibitions with a permanent installation allowing visitors to experience and learn various aspects related to crowd simulation. The system will be based on a crowd simulation framework developed in our research group. This framework covers everything from the AI for global planning to local animations and modelling of realistic crowd behaviors based on agent profiles and semantics such as terrain annotations [4], [5]. Yet, it lacks an interface that is easy to operate and suitable for a presentation in a museum.

The *purpose of this installation* will be twofold. First, it should educate people about the complex, dynamic systems embodied in crowd simulation. It should create awareness, for example, to help them reflect on their own behavior in crowds, but also to illustrate the challenges and difficulties city planners or event organizers are faced with. Second, the museum also focuses on engaging the public in the process of science itself, and connecting them to actual research. Thus, the installation should also be used to teach people how simulations are used for scientific research.

Due to its educational purpose, the presentation should be *interactive*. Visitors should be able to place obstacles, such as buildings or barriers that cannot be crossed, sources where crowds emerge, such as bus stations, and targets where crowds move to or gather, such as food stalls at a festival. The target audience for this museum presentation varies significantly – ranging for example from very young kids at pre-school age to senior citizens. Thus, the system needs to provide an *easy, simple, yet powerful interface and interaction design*.

Finally, the installation itself should be able to deal with crowds, that is, *large amounts of visitors* as we anticipate larger groups, such as school classes, where each individual wants to explore the system and play with it. This, and the varying age ranges, also pose high requirements on the *robustness* of the implementation, since we cannot expect, for example, very young kids to always follow certain rules or behavior when interacting with it. People will use it in various ways, including things that push its limits and have not been anticipated by the system designers.

III. AR installations – AR Table & Handheld AR

The requirements above were identified by our own observations at different interactive museum installations, demonstrations of preceding AR prototypes that we developed, and the feedback and comments from people at the museum where the installation will be placed. Based on these and the analysis of different immersive technologies presented in [3], we decided on a spatial AR installation in the form of a table where AR content is projected from the top, and an additional handheld AR component that is accessed and operated by visitors via an app on mobile phones.

Spacial AR projects virtual elements onto reality, thus augmenting it with virtual visuals. Common installations include tables where a data projector is mounted on the ceiling. Fig. 1 shows an example of an earlier demo of our system with a fixed city model. The new installation for the museum uses a mobile setup where people can place obstacles and other objects, both real and digital, onto the table.

Fig. 1. AR table installation with data projector and video camera on the ceiling and projections onto a fixed city model.

The advantages for using an AR table at the center of the presentation are obvious. First, it attracts visitors and is visible to many at the same time, as opposed to computer screens or AR glasses that can only be used by view at a time. Users can interact via tangible interfaces [6] (e.g., physical objects placed on the table) or touch interactions for digital content. Because touch is omnipresent in smartphones and tablets these days, we expect it to be the best interaction metaphor for all our target user groups. It also supports multiple users interacting at the same time.

Yet, places at this table that are close enough for users to interact with its content are limited. Also, actions done by individuals to support their learning process (e.g., overlay of meta information) might interfere with the learning process of others. While certain parts of the simulation should be visible to everyone, a personalized view of some information might be desirable in certain situations as well.

For this reason, our AR table is complemented with *handheld AR*, Where the visitors in the museum are able to make use of an AR app, provided by the museum that shows a live image of the AR table (via the phone's camera) augmented with virtual information on the screen. Fig. 6 shows an example where the flat objects on the table are shown on the phone in 3D and additional information about a particular object on the table is given ("Supermarket"). This solution is technically challenging, because it combines two AR systems, and realizes new concept for AR interaction, because it augments (via handheld AR) and already augmented reality (the AR table), thus technically realizing an 'Augmented AR' system (AAR).

IV. Implementation

A. AR Table

There are several existing implementations of AR tables using data projectors to create and interact with mixed realities, that is, virtual and physical objects. Some of them just project digital content onto physical surfaces, similar to our implementation shown in Fig. 1. The final installation in the museum should however allow people to interact with a crowd simulation by both physical and virtual objects. We envision a solution where the museum provides certain blocks or obstacles, visitors can place their own physical objects on the table, or use a menu to place and manipulate digital elements via multi-touch gestures – all smoothly integrated into one experience. From a hardware point of view, this requires the actual table (along with physical objects), a data projector creating the virtual parts of the simulation, and a camera for tracking the physical objects as well as hands of the users to realize multi-touch interaction. Our current installation uses Kinect cameras for tracking, but can be extended to use alternative cameras such as the Intel RealSense if needed. In the following, we describe our implementation.

Calibration. The first step in realizing such a table is the calibration of the system, which aligns the camera space (i.e., the space of the table that is visible to the camera for tracking) with the projector space (i.e., the part of the simulation that is projected onto the table), and the simulation space (i.e., the 3D environment running the simulation on the computer). We are using a standard approach that detects the corners of the table to define the camera space. The projector space is determined by recursive line drawing, and both spaces are mapped using OpenCV's wrapPerspective function (see Fig. 2).

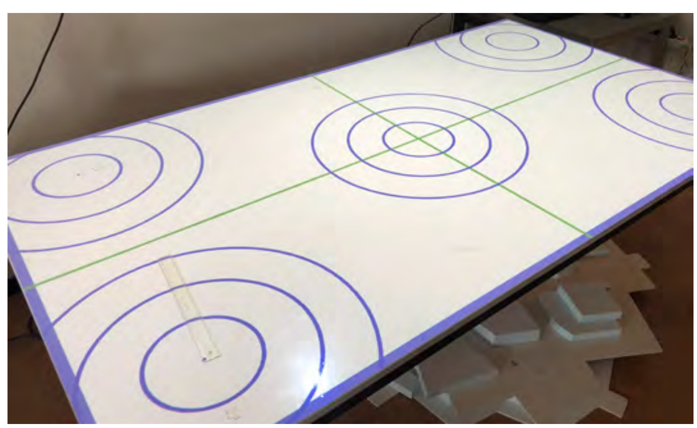

Fig. 2. Calibration of the AR table.

Interactive contour detection. Visitors should be able to place random physical objects on the table, which will then serve as obstacles in the crowd simulation. Thus, we need to recognize those. Because the simulation is done on the flat surface of the table, it is sufficient to detect each object's contour and ignore its actual 3D shape. A future version should include 3d shape recognition though in order to be able to project additional information (e.g., names on the top of buildings) and texture onto them (e.g., facades and roofs for buildings to make the simulation look more realistic).

We distinguish between 'fixed objects' that are placed on the table to serve as an obstacle that the simulated crowds have to walk around, and 'dynamic objects', such as the users' hands that are used for interaction. Fixed objects include 3D objects, such as toy blocks, as well as 2D objects, such as obstacles drawn on a piece of paper. The scene on the table is constantly re-evaluated and updated in almost real-time using the 8-bit RGB image, the 16-bit infrared image, and the depth image captured by the camera. Fig. 3 shows a contour map created from the physical objects placed on the table, along with several virtual source and target locations for the crowd simulation. Fig. 4 shows the contours used to create multi-touch functionality to enable placing and modifying these (and other) virtual objects and controlling the simulation.

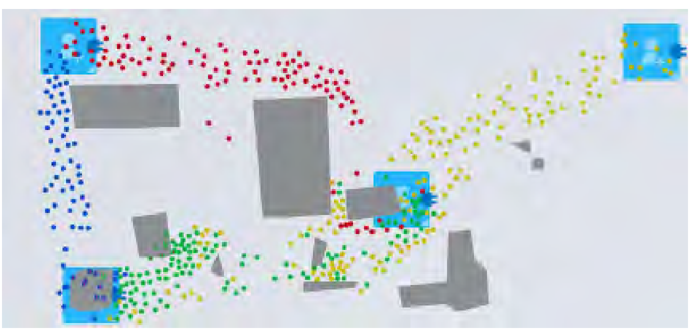

Fig. 3. Contour map of the physical objects placed on the table.

Interactive multi-touch interaction. The ultimate goal is to provide robust touch interaction for as many users as can possibly fit around the table, also considering a very robust recognition dealing with things such as overlapping arms or hands by different users and unintended user behavior (e.g., competing kids grabbing or hitting each others hands).

Our current approach to detect and track the users' hands is based on the method presented by R. Xiao et al. [7]. It is able to recognize a touch performed by a hand that has a pitch angle x from the surface of $0 < x < 70 \pm 10$ degrees. Initial testing showed that it works fairly robust, but further tuning and improvements are needed in order to process also the uncommon and unintended inputs mentioned above.

Virtual elements and simulation environment. Placement of virtual objects, including ones that control the actual simulation (e.g., sources where crowds emerge) is done via menus that are optimized for table top interfaces (Fig. 5). These menus and the virtual objects themselves are also used to control and modify the actual simulation (e.g., change number or speed of spawning crowds, define start and target areas).

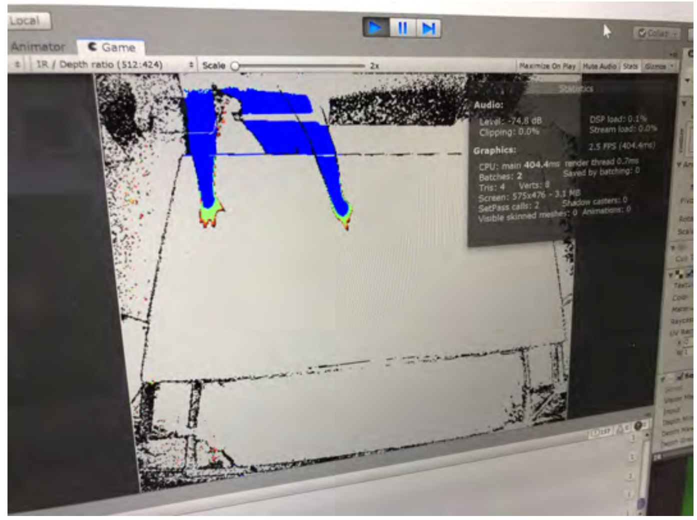

Fig. 4. Contour detection for creating multi-touch functionality.

Fig. 5. Table top interfaces to control the simulation.

B. Handheld AR

In addition to the interactive AR table, visitors of the museum will be able to use an accompanying AR app on mobile devices (smartphone). The motivation for this is first, to offer an alternative interaction mode in situations when there are too many people making tabletop interaction not feasible anymore, and second, that people are able to explore personal views and information that might be relevant for them but not to others.

Our initial prototype of this 'Augmented AR' concept runs on Android phones and uses the Google's ARcore platform [8]. The ultimate vision is an app that allows users to interact with the simulation environment on the table as well as show additional information (e.g., statistics about crowd densities or density maps, information about obstacles or events to happen) on their personal screens. Our current proof-of-concept implementation overlays flat 2D simulations of pedestrians and buildings on the table with their 3D versions. Information about buildings is given, and individual pedestrians can be controlled via the app. Future interactions with the simulation environment will include standard controls of the simulation (e.g., modifying sprawling speed) as well as further manipulations of individual characters or groups of them.

This vision is a promising, but also very challenging interaction concept, requiring various new approaches in interaction design due to the simultaneous control of two augmented environments (the one on the table and the one on the phone). Thus, in our first implementation, we focused on the equally challenging technical difficulties, and will address the interaction design in our future work. As a prove of concept, our current version allows to visualize flat physical objects on the table as virtual 3D objects on the phone, and to present additional textual information for each of them (see Fig. 6).

Major technical challenges include accurate tracking of the AR table's surface, which may be partly blocked by the hands of people interacting directly with it. The app on the phone needs to have constant access to the simulation on the table, and handle potential updates from phones used by other visitors running the same AR app and interacting with the system as well. Our implementation tracks the real-world position of the table using the fully rendered projected image, which is created at the end of every update loop by the main application, as marker. To calibrate for this 'dynamic marker', an additional fixed marker is used, which is permanently placed on the table. User interactions on the phone, albeit limited in the current implementation, are processed in real-time and exchanged with the main simulation on the table.

Despite its prototypical status, our implementation runs fairly robust. Performance testing revealed network traffic and resulting delay as a potential bottleneck that needs to be addressed in the future. Other issues requiring attention include the influence of changing lighting conditions as well as user testing under 'extreme' conditions, that is, numerous users with multiple hands on the table that are constantly moving around. Fig. 6 shows an example of the implementation with two users. Here, the interaction takes place with a testing system running on an HP Sprout computer that provides the same functionality as our interactive AR table.

Fig. 6. Two users interacting with the tabletop simulation via the AR app on mobile phones.

V. Conclusion

We presented a system for accessing, exploring, and manipulating crowd simulations via augmented reality in the context of a museum presentation. The goal of this installation is to teach visitors about crowd simulation and the scientific principles of simulations. The chosen AR concepts are based on our analysis in [3], which resulted in the creation of an interactive AR table, complemented by a handheld AR solution. The table proved to be a viable and promising solution in initial informal user tests and feedback provided by experts from the museum. Our future plans include optimization of system performance, implementation of additional features, and extensive user testing with potential end users before the system will be installed in the museum. The handheld AR solution allows for an individual, personalized view of the simulation and a remote control and involvement for people who are not directly standing near the table. Our current implementation addressed the technical challenges that have to be overcome with such an innovative setup. Further optimization as well as exploration of new interaction designs and possibilities to experience crowd simulations are part of our future work.

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