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A Virtual Reality Framework for Human-Virtual Crowd Interaction Studies

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***Abstract*—In this paper we developed a generic framework for authoring virtual crowds with minimal effort. Our intention is to providing to the virtual reality community a framework that allows easy to author virtual crowd scenarios that can be used for human-crowd interaction studies. From previous studies we have conducted, we realized the need of such a framework as it facilitates quicker setup and testing as well as standardizes the measurements and the interaction with virtual crowds. The framework includes assets with realistic human models, and configurations for crowd behavior composition.**

***Keywords*-virtual crowd; crowd authoring; virtual reality; human-crowd interaction; experimental studies;**

I. Introduction

In modern society, humans find themselves needing to navigate through a crowd and our responses to them can tell us a lot about human behavior. There is a lack of parity between interacting in the real and the virtual [1] world and understanding the differences between them will be crucial as virtual reality gains prominence. Understanding human behavior in interaction with crowds can provide useful insight into how we might manipulate not only their physical patterns like trajectory, speed, and avoidance behavior but their psychological and physiological states.

Navigating crowds is an understudied field in virtual reality locomotion and as such would benefit from the development of a standardized framework for research. As crowds are a dynamic entity, they have the potential to alter the movement patterns that humans engage in. Because researchers may be collecting data in various ways, we believe it is valuable to have a standardized framework to collect this data and to quickly and efficiently conduct new experiments. To that end, we have developed a generic framework that can be expanded upon to conduct experiments in how various patterns and compositions of a crowd can influence the movements of people physically walking in a virtual space (see Fig. 1).

The developed framework was implemented in Unity game engine and can be implemented in any virtual environment. The goal of this project is to provide a publicly available framework for the research community using the Unity, a publicly available game engine. The framework provides for much easier initial crowd setup as many patterns and variations are configurable, such as density, speed, and crowd destinations and waypoints. It also provides out of the box human performance metrics such as time to cross, speed of crossing, under and over taking behaviors, crowd avoidance behavior, trajectory length, and more.

The paper is structured as follows. In Section II, we provide an overview of previous research into human interaction with virtual crowds. In Section III we explain the functionalities of the framework and what information is recorded. Finally, in Section IV, we conclude the paper with an overview of the frameworks applications and what additional improvements and features we intend to develop in the near future.

II. Related Work

Various studies have been conducted to understand the interactions between humans and groups of virtual characters [2–5]. The areas of interest in these studies are wide-ranging and encompass many facets of both movement and perception. Following behavior [6, 7], side-by-side [8], face-to-face walking [9], flocking behaviors [10], trajectories [11, 12], and collision avoidance [13, 14] have been explored in the past few years. An important aspect of movement within a crowd is coordination and collective behavior [9, 10]. We know that participants keep a larger distance from virtual characters when they are tightly packed [15] and in general, try to take a longer path around dense crowds [16].

Movement patterns have been measured in several ways, with speed being the most important [17, 18]. In addition, other performance criteria [19, 20] such as time of completion, distance traveled, and empirical observations [20] have been extensively used in the past. Previously conducted studies [16, 21] have shown that the density, speed, and global crowd direction have an impact on the speed, direction, and trajectory lengths of participants surrounded by a moving virtual population. Moreover, it has been found that participants tend to match their velocity, rather than keep a constant distance when following a crowd leader [22].

Participant's perception of realism is another aspect of crowds that is widely studied. Olivier et al. [23] developed a different virtual reality framework to examine the realism of simulation algorithms. Dickinson et al. [24] studied the effects that the density of a crowd can have on the emotional states of participants where they showed that interacting with

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Figure 1. A preview of a scenario in the framework that a participant will see when walking within a virtual crowd.

high-density crowds have a significant increase in negative affect. It has been found that grouping characters together in a crowd that contains the proper size and number of characters has a positive effect on the perception of realism of the virtual crowd [25–27]. The absence of collision avoidance or shaking artifacts of virtual characters have also been shown to invoke a low level of comfort and presence [28, 29].

By conducting this literature review, we concluded that this framework is a logical next step for many of the studies mentioned previously. Each study that deals with human-virtual crowd interaction uses its own implementation and we realised there is no standardized framework the community can use. Many would have benefited from a framework that allows for ease of setup and already included metrics for evaluating variations of crowd behaviors on human participants. For this reason, we created this framework to fill the gap and provide an easy-to-use and easy-to-extend platform that can be levered by both experienced and inexperienced virtual reality developers and researchers.

III. The Framework

The framework (see Fig. 2) is divided into a few classes. A main `GameController` manages the overall game state, the `Pedestrians` in the crowd, and the `Participant`. It is configured with a `CrowdController` that defines the various trials the system will test and an `AreaController` that defines the area the participant and crowd will navigate in. The `Participant` feeds its tracked data through the `GameController` to the `DataManager` where it is recorded for analyses.

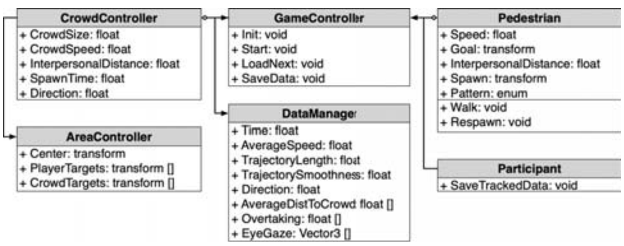

Figure 2. Summarizes the system architecture the framework is designed with.

A. Setting Up the Virtual Environment

A generic city model is included, but a researcher may import his/her own model of a virtual environment. The crowd uses the Nav Mesh functionality of Unity game engine, so it is required to choose all of the destination waypoints in advance (see Fig. 3). Unity's collision avoidance uses Reciprocal Velocity Obstacles (RVO) [30], and alternative improved algorithms such as RVO2 [31] and Hybrid Long-Range Collision Avoidance [32] are planned to be included in subsequent releases. In the base case a four way intersection scenario is presupposed such that agents in the crowd can walk to and from any corner or middle of an edge to each other. It is not necessary to utilize all of the waypoints, and the ones used are chosen when setting up a trial. The user also sets up the start and end positions that the participant will walk between. For the crowd, the user should define the start and goal positions as well as intermediate waypoints to help alleviate congestion. Once set up and participants are placed at the aforementioned defined start points. An audio or visual cue is then given to either begin walking and again when they've reached the target position to cue a halt.

Figure 3. Spawn locations as seen in the developer view. Location indicators will not be shown to the participant.

B. Setting Up the Virtual Pedestrians

The framework includes 28 human models (14 male, 14 female), but any number of additional models can be included or swapped in depending upon the needs of the researcher (Fig. 4). More human models, textures, clothing, and walking animation variants are planned to be included from motion captured data in subsequent releases. The intention of these models was to provide virtual characters with enough realism, but still be light-weight enough to run on lower end head-mounted displays. Realism of virtual characters has been shown to have effects on participant's perception and their immersion [33]. To that end, the models all come in variants of ethnicity and clothes to further help with the realism of the virtual environment.

C. Framework Functionalities

The framework makes some assumptions on how a researcher will conduct an experimental study. The first of these are the physical requirements needed to conduct a walking study. The researcher needs an adequate space in which a participant is able to walk in. They also need either a cordless head-mounted display that supports either OculusVR or SteamVR such as the Oculus Quest or HTC Vive with its wireless adapter, or a backpack computer. This is to ensure free range of movement of participants.

When setting up a study, the participant will be instructed to stand in a specific space and move to a target position. After stopping, the user will be prompted to either turn around to walk in the next trial or remove the head-mounted display as the study has been completed.

Each crowd has a given set of parameters that the researcher is able to change:

- **Crowd Size:** The max number of individuals a crowd will contain.
- **Crowd Speed:** The max speed that each individual of the crowd can walk.
- **Interpersonal Distance:** The minimum distance that an individual of the crowd can approach each other and the participant. This is calculated from a radius.
- **Spawn Gap Time:** How fast to spawn a new member of the crowd. This is measured in seconds.
- **Spawn Radius:** Defines the circular area in which members of the crowd will spawn around their spawn points.
- **Direction:** If the researcher wishes to have a deviation to the target position that the crowd can walk, this is accomplished with an offset measured in degrees.

Members of the crowd are also able to be assigned various walking patterns that they are able to walk in. A square area is defined by the researcher in the virtual space by a location and walkable area. The walkable area has 8 spawns located at the corners and center edges and 12 final target positions in which the members of the crowd can navigate between. The paths are predefined by various `booleans` that set members to spawn at specific locations. Each location will walk to the opposite location and then to a node out of sight from the user before returning to the spawn. This path can be changed to walking around the square clockwise, diagonally, or include turns such as dogleg left and right. It is also possible to have crowds come from multiple directions at the same time (Fig. 5).

D. Data Acquisition

The framework includes a few out of the box tracked metrics. Data is collected every .10 seconds by default as we have found smaller increments to not add to meaningful analysis. All data is reported at the end of each trial automatically. Any additional metrics can be easily extended to the framework, but the included methods are:

- **Time and speed to cross:** This is measured from when the participant is instructed to walk until they reach the destination node.
- **Trajectory length:** The total length that the participant walks between start and end nodes.
- **Trajectory smoothness:** The deviation from a straight path.
- **Direction:** The total deviation from the target node when reaching the other side.
- **Average distance to Crowd:** Measures the five nearest neighbors to determine the distance to the crowd for avoidance behavior.
- **Over/undertaking behavior:** Measures if the participant is passing members of the crowd or being overtaken by them.

We also allow for additional data collection through using various libraries. We have found a common need to provide measurements that relate to functions other than movement such as eye-tracking data and electrodermal activity.

- **Gaze data:** Our platform supports eye-tracking functionalities through the use of an HTC Vive Eye Pro head-mounted display, which has embedded eye-tracking capabilities. Using this device, we are able to capture eye gaze data (e.g., fixation, gaze points, heat maps, areas of interest) that can later be used to understand where and how people focus during interaction with virtual crowds.
- **Electrodermal activity:** Our platform supports physiological data capture (electrodermal activity) in order to investigate people's emotional reactions when interacting with virtual crowds.

IV. Conclusions and Future Work

We developed a generic virtual reality platform in which to run crowd studies of many variations. A universal tool such as this will prove beneficial to the community of researchers who are interested in crowd-human interactions in virtual reality as it enables quick setup and prepackaged performance metrics for many studies. In addition, it allows for building new variant studies to be built upon. Unfortunately, it is not possible to include every scenario that a researcher would desire to test as there are too many possible variants. In the future we intend to include more configurations such as ethnicity variations, characters with

Figure 4. The virtual characters that were designed and provided with our framework. In total there are 28 (14 male and 14 female) characters.

Figure 5. An example of crowd variants that the user may configure.

masks, size and height variations, static bystanders, sub crowd behaviors such as families and uniform distributions, additional pathing and collision avoidance algorithms, and more advanced real world interactions like slopes and traffic.

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