Orchestrating an Interactive 3D Holodeck

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Abstract

Enabling an interactive 3D holodeck poses significant challenges in the networking of thw swarm, due to the density and latency requirements. In this paper, we envision an orchestration mechanism using visible light communication and dynamic clustering for actuation.

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3D Holodeck. A 3D holodeck [3] is a physical 3D display that illuminates the shape of an object or a scene of objects. A digital version of the 3D holodeck is often referred to as a 3D volumetric hologram, which shows great potential and attracts huge interest in the augmented reality (AR) and mixed reality (MR) [5–7, 10] community. Taking a step further, a physical holodeck can not only bring the virtual hologram into reality, but also enable its interaction with the real world. For example, two humans can use a 3D holodeck to play chess, and a humanoid one can assist with household chores.

One approach to envisioning a physical holodeck is to use a swarm of flying light specks (FLS) [4]. Each FLS is a miniature-sized drone, equipped with light sources for display, wireless radio for network, and a microcontroller unit (MCU) for compute. The swarm of FLSs can be pre-programmed to illuminate either static shapes, or an animated sequence, similar to many large scale drone light shows [8], and live hero animation in popular esports games.

Figure 1: Mock-up of an animated sequence [9].

Interactive Holodeck. In addition to static and pre-programmed dynamic display, the key attraction of a 3D physical holodeck is its capability to interact with the world. These interactions enable a variety of novel applications; a real life Pokemon Go game, a holodeck for any interactive board game (*e.g.,* Jenga, Catan), a home assistant that can put away stuff as commanded, *etc.*. The interaction can be initiated by both the holodeck itself and the outside world; in the Jenga game, once the human player pushes one block, the whole block would move along; in the case of home assistant, part of the holodeck needs to move together to push, pick up, or drop the target.

Orchestration Challenges. *Latency.* To accomplish the interactions described above, parts of the holodeck need to be coordinated to move together. Such coordination is triggered by arbitrary interaction thus the reaction and actuation cannot be pre-programmed. The orchestration of swarms of FLSs needs to happen in real time.

FLS to Orchestrator. Ideally, an orchestrator should have bi-directional communication with FLSs; for instruction and feedback. However, due to the density, RF based communication is prone to severe interference, either among FLSs (*inter-FLS* for a distributed orchestrator), or between FLS and a server (*uplink* for a centralized orchestrator). Therefore, it is challenging to get FLS feedback.

Orchestrator to FLS. It is not scalable for the orchestrator to give instructions to each individual FLS. The downlink capacity will quickly saturate as the number of FLSs increases. In other words, it is impractical to talk to, in real time at a high frequency, swarms of FLSs with individual instructions.

System Design. The orchestrator includes three components; Monitor, Instructor, and Physics Simulator.

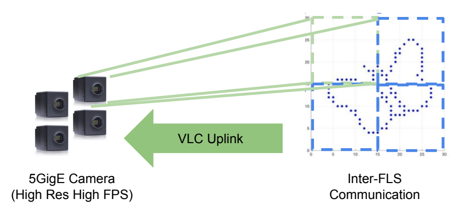

Figure 2: Scalable Holodeck Monitor. An array of high frequency cameras functioning as VLC receivers to monitor FLS ID and position.

Figure 3: Mock-up of mesh clustering for group instructions [1].

Monitor. Instead of RF, visible light communication (VLC) provides a nice alternative for the uplink. Each FLS can modulate their ID onto their light source such that a high frequency camera can decode and register each FLS's location. These locations can be fed back to the instructor as a reference for the next frame. An array of cameras can scale up the holodeck, each monitoring a voxel of 3D space (Figure 2). Though each individual link capacity is low compared to photo-diode receivers, cameras can establish massive amount of parallel connections.

Instructor. To simplify downlink instructions, the instructor clusters FLSs into groups of connected components (Figure 3). Only one transformation matrix (describing translation, rotation, and scaling) is given to each group, such that the FLSs in the group can calculate their destination positions based on current locations. Depending on the animation granularity, the instructor can use 3D mesh simplification methods [2] to segment the holodeck into coarse groups of large parts or fine-grained groups of detailed components.

Physics Simulator. The orchestrator keeps a digital twin of the holodeck in the physics simulator. Interactions are simulated in the digital twin, of which the results are forwarded to the instructor. The results can guide the instructor on dynamic clustering. For example, an external force may break the cluster such that part of the cluster need to move in a different direction. The physics simulator can inform the instructor to reconfigure the cluster such that two separate parts can be transformed differently.

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