Multi-User Augmented Reality with Communication Efficient and Spatially Consistent Virtual Objects

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Multi-user Augmented Reality

- Pokemon Go Buddy Adventure
- Minecraft
- CloudAnchor
- Just a Line
- VINS-AR*

Initialization Latency

- We define the time from the host start sharing the virtual object to the other user(s) finish relocating the virtual object as the initialization latency.

1. Alice places virtual object
2. Bob sees virtual object

User-perceived end-to-end latency

Time
A large chunk of data has been sent during initialization process. What has been set? Can we speed up this process?
Drift/spatial inconsistency
A light review of Background

• Current AR platforms such as Google ARCore, Apple ARKit, and Microsoft Hololens rely on simultaneous localization and mapping (SLAM).

1. Extract features and construct a point cloud
2. Estimates camera location and orientation (pose)
3. Project virtual object and draw it on the screen
Coordinate system alignment

[Diagram showing the process of coordinate system alignment]

- **World coord. system (host)**
  - Input: $p_A^{\text{world}}$
- **Device coord. system (host)**
  - $R_A, t_A$
- **World coord. system (resolver)**
  - Output: $p_B^{\text{work}}$

**Comparison:**
- **Traditional single-user PnP**
  - Point cloud
  - Resolver
- **Proposed multi-user PnP**
  - Point cloud
  - Resolver
  - Host
Sending strategies

SPAR-Small: Only send frames that are less than 1m away from the virtual object.

SPAR-Large: Only send frames that virtual object is shown on the frame.
User mobility pattern

**Scenario 1**
- Host
- Resolver
- Distance: 1m

**Scenario 2**
- Host
- Resolver
- Room: 2m

**Scenario 3**
- Host
- Resolver
- Distance: 1m
Sending strategies Results

SPAR-Small can reduce initialization latency up to 55% in scenario 1 and 2.
Spatial inconsistency can be reduced by up to 60%.
Update strategy

feature geo distance: the average distance to a virtual object over the common features in a pair of matched keyframes

\[ p_B = (x_B, y_B, z_B) \]

Point cloud keyframe features

Features matched with host

Resolver
Update Results

Use matches with low geo-distance can have less spatial inconsistency
A tool for drift/spatial inconsistency measurement

Environment setup
Tool Results

Spatial Drift (cm) vs. Keyframe Index

3D Scatter Plot: X, Y, Z coordinates with trajectories shown in red and blue.
Tool Results

The tool can have a good estimation of spatial drift.
Key Take-Aways

- Efficient communication strategies: SPAR-small and SPAR-Large
- Virtual object update strategy: use matched frames with low geo distance
- A tool to estimate virtual object drift