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RetroSphere

Self-contained Passive 3D Controller Tracking for Augmented Reality

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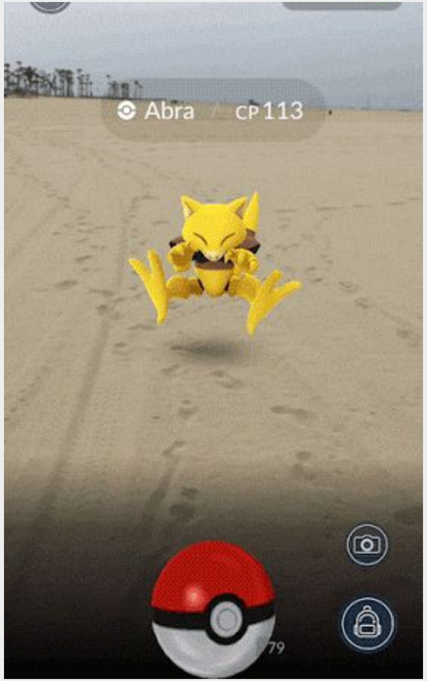
[$]*This work was done while the author was interning at Google.*

Smartphone Augmented Reality (AR)

AR Interaction (DepthLab, UIST’20)



AR Gaming (Pokemon Go)

AR Shopping (IKEA Place)

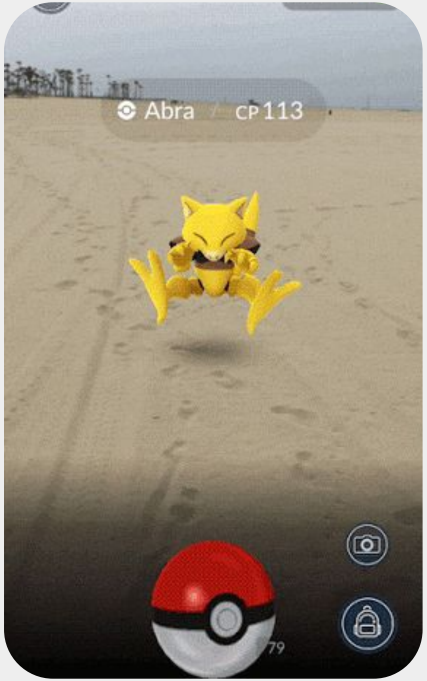
ARCore

ARKit 5

Background

Smartphone AR applications

AR Interaction *(DepthLab, UIST'20)*



AR Gaming *(Pokemon Go)*

AR Shopping *(IKEA Place)*

ARCore ARKit

Background

Augmented Reality Glasses

Meta AR glass concept
(Project Nazare)

Vuzix Blade

Microsoft Hololens 2

Magic Leap 2

Compared to Smartphones and VR headsets, AR glasses are

1. **Resource-constrained** (both battery and compute capacity)
2. **Thin and Lightweight form factor**

AR glasses still lack 3D inputs for interaction with the AR user interface.

Background

3D Tracking approaches in VR/AR headsets

Existing VR/AR tracking approaches incur **high power consumption** or are **computationally expensive**.

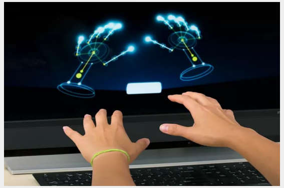
Electromagnetic tracking

Auraring

Infrared camera based tracking

Oculus Quest 2

Camera-based hand tracking

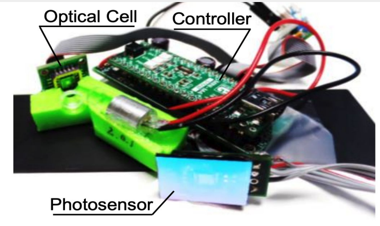


Leap motion (Stereo Infrared camera and IR LEDs for hand tracking)

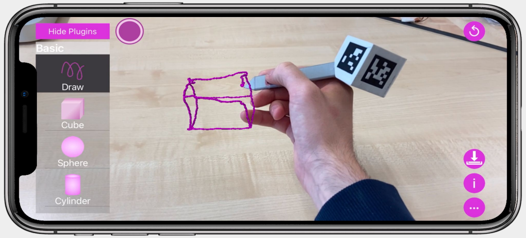
Stationary infrastructure

HTC Vive

Laser/MEMS based tracking

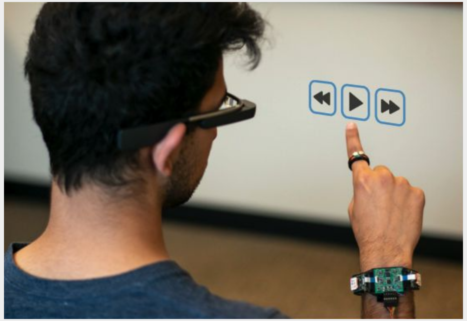


Smartphone camera based tracking of a cube marker



ARPen/DoDecapen

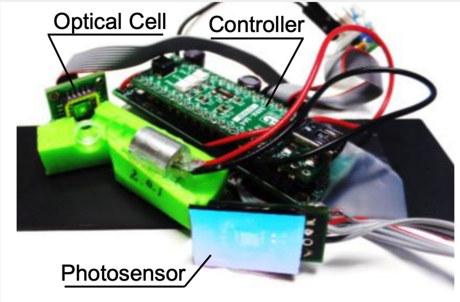
3D Tracking approaches in VR headsets



Auraring (Electromagnetic tracking)

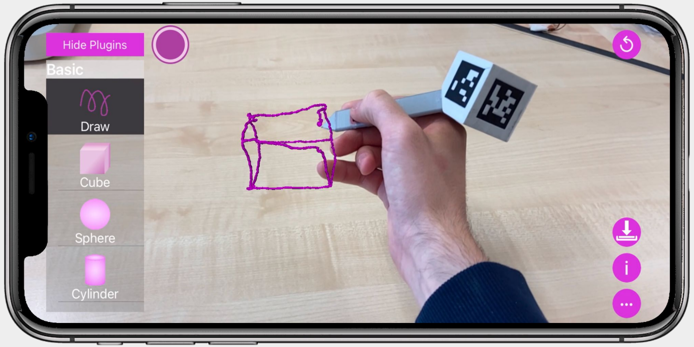
Oculus Quest 2
(Infrared camera based tracking)

HTC Vive
(Infrared camera based tracking)



Laser/MEMS based tracking

Leap motion
(Stereo Infrared camera and IR LEDs for hand tracking)



ARPen/Dodecapen
(Smartphone camera based tracking of a cube marker)

Background

3D tracking with AR glasses v.s VR Headsets

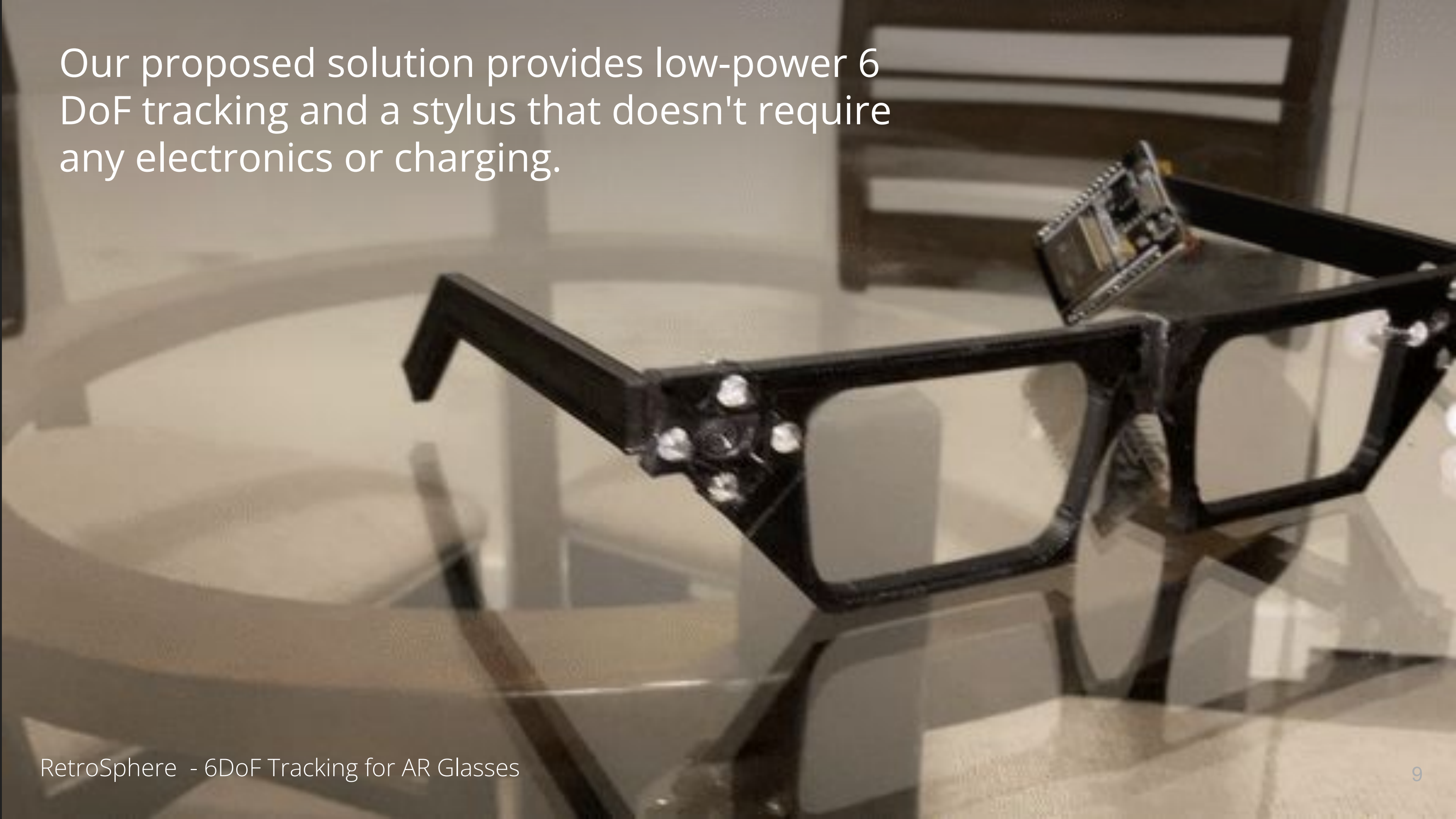
- significant power and computation.
- not very portable for everyday AR use cases

VR based hand tracking and other continuous camera-based tracking isn't possible given the limited compute power and battery capacity.

Problem Statement

Low Power 6DoF Tracking

Need for a low-power and low-compute self-contained 6DoF tracker that can provide spatial input on future resource-constrained AR devices.



Our proposed solution provides low-power 6 DoF tracking and a stylus that doesn't require any electronics or charging.

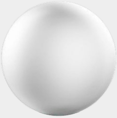
Enable spatial 3D interaction on portable devices with form-factor and power constraints.

Solution

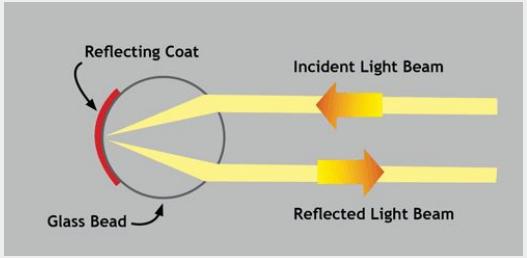
RetroSphere

Our solution is self-contained and can augment existing AR glasses for prototyping purposes or built into future products.

System Design
Passive Retroreflective Markers



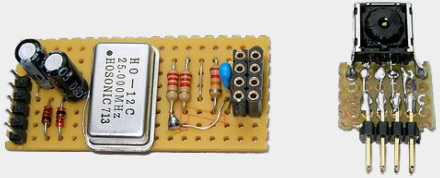
A Retroreflective Marker



Retroreflectivity

Retroreflective markers are used in motion capture systems such as Optitrack, Vicon etc.

System Design
Infrared Trackers



Wiimote IR tracker

An **IR tracker only tracks IR light emitting sources** unlike an IR camera. In addition, IR trackers are **tiny and consume low power**.

Johnny Lee (Head Tracking with IR trackers)

3D tracking of a Wiimote IR tracker(Franklin Ta)

System Design

RetroSphere Tracking Hardware

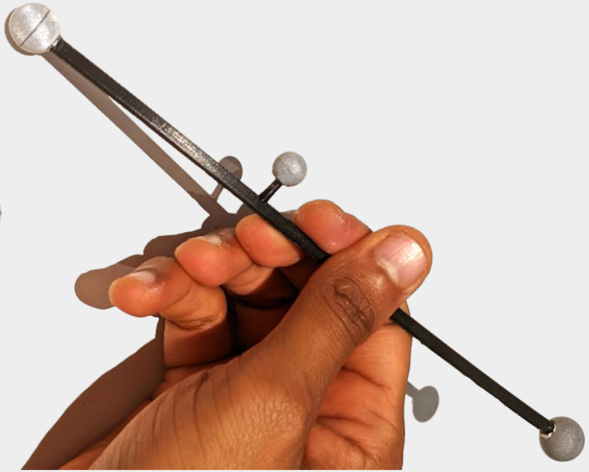
Stereo infrared blob tracking cameras

On-device 6DoF estimation pipeline for tracking our RetroReflective stylus

Colocated IR LED illuminators for tracking our retroreflective stylus

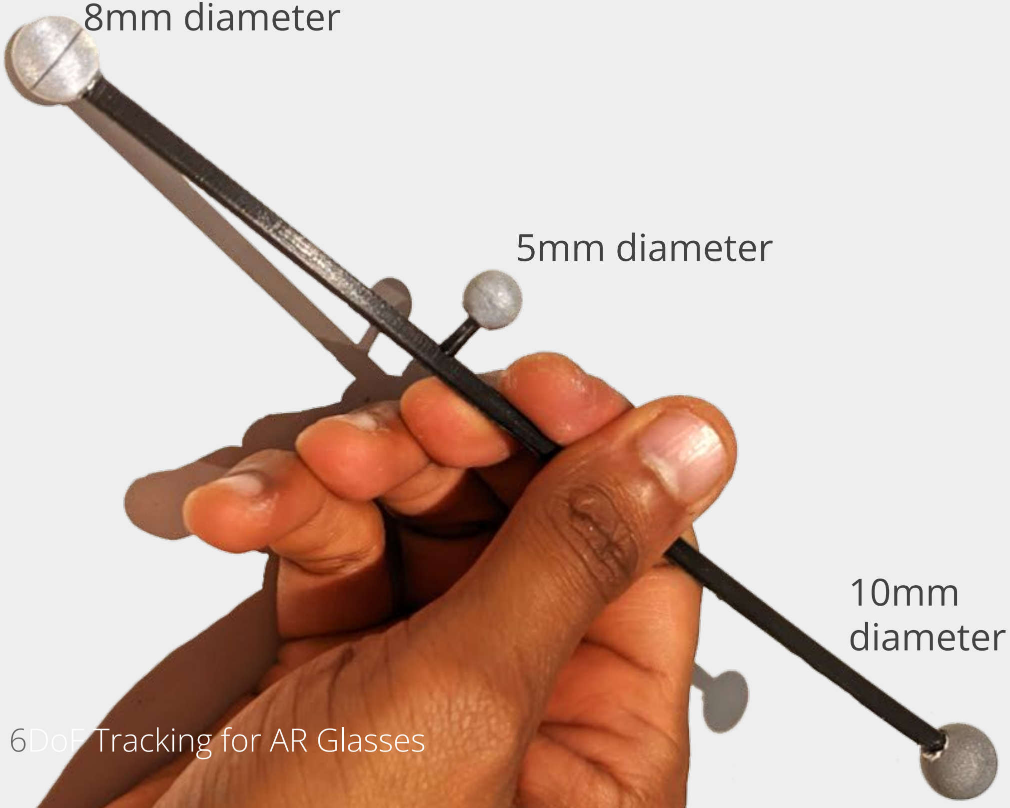
- **Always-on low-power 6DoF tracking hardware**
- **Low-cost and affordable hardware**
- **Easy integration into future AR glasses**

RetroSphere - 3D Tracking Hardware



System Design

Passive Retroreflective Stylus

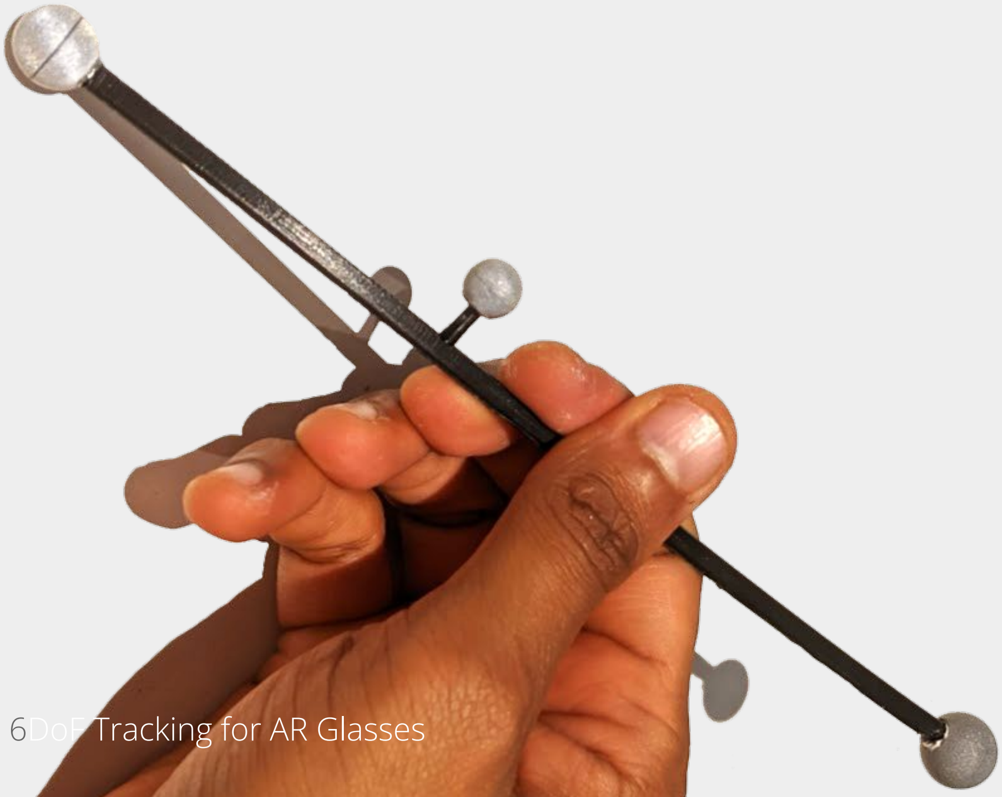


Passive stylus -
consists of 3 Retroreflectors each of unique size and triangular geometry

Supports 3/5/6DoF tracking

It can be easily integrated into other form factors such as wristband, pencil, ring etc.

Passive Retroreflective Stylus



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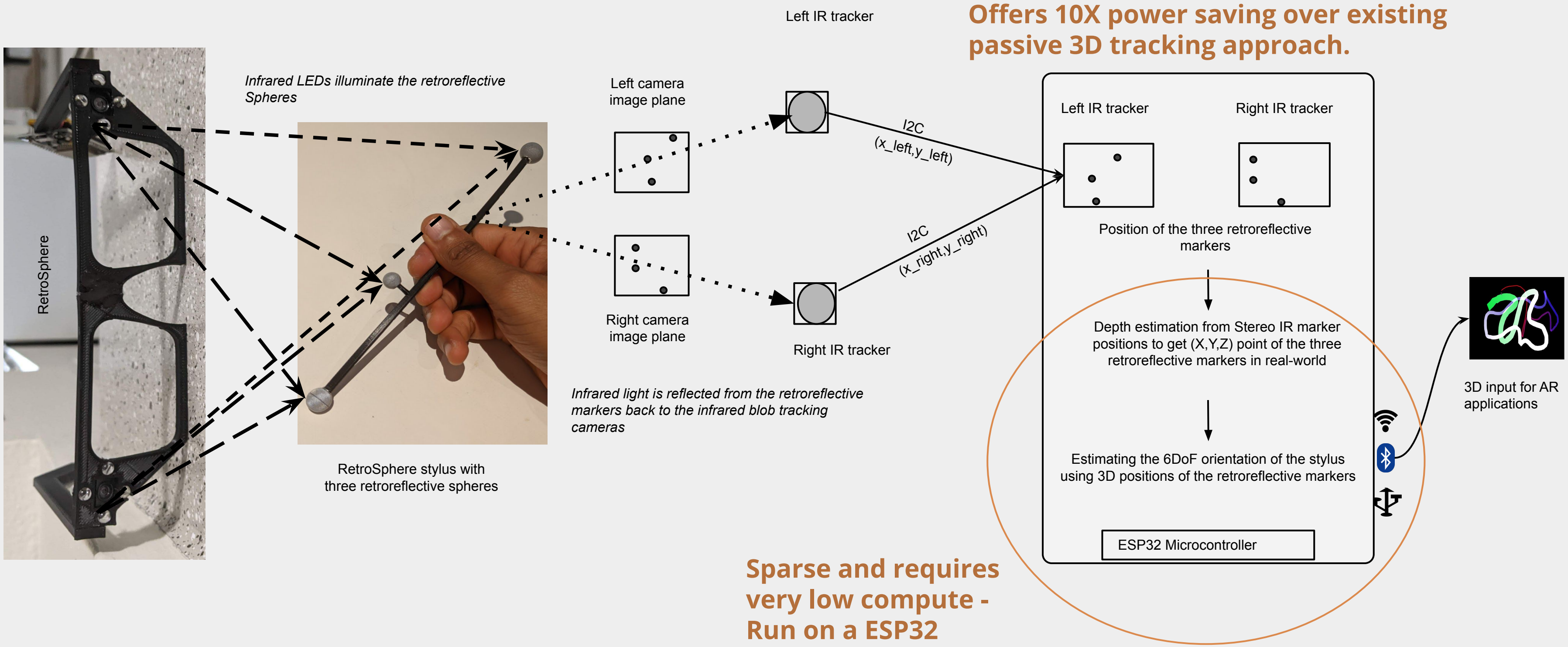
System Design

Overview of RetroSphere



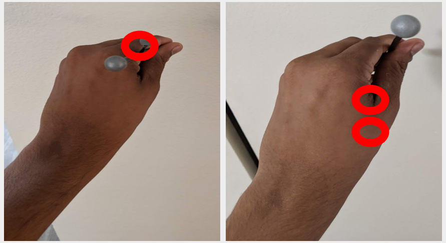
System Design
RetroSphere Tracking Algorithm

Automatic calibration procedure

User randomly waves the stylus in mid air while wearing RetroSphere glasses (for 10-30 seconds).

→ Stereo 3D Depth estimation approach

→ 3D coordinates of observed markers →

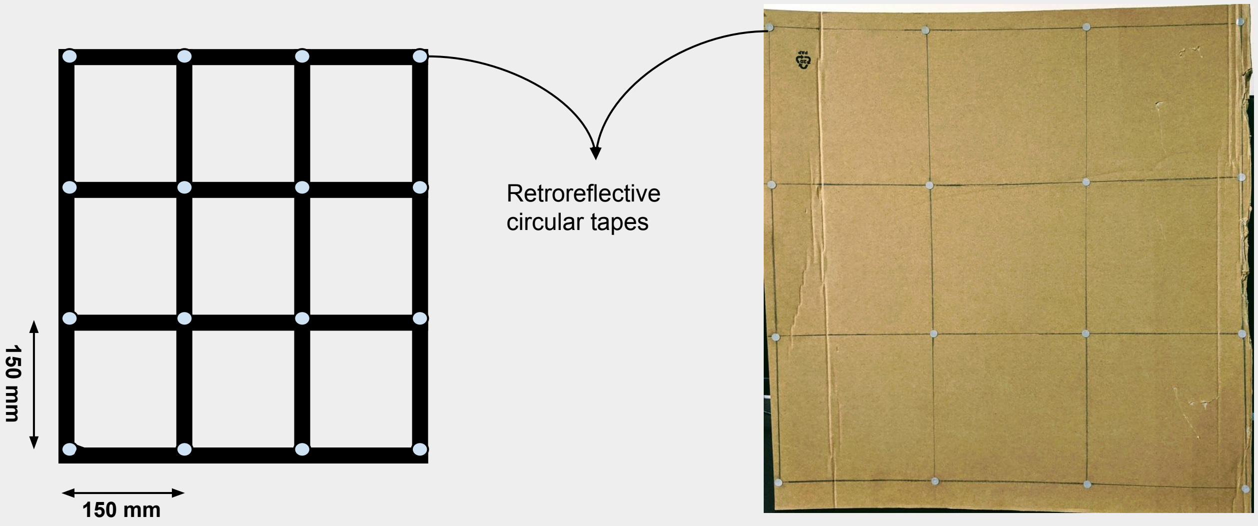


Neural network based prediction of occluded marker positions

↓ 3D coordinates of all 3 retroreflective markers

6DoF orientation of the stylus

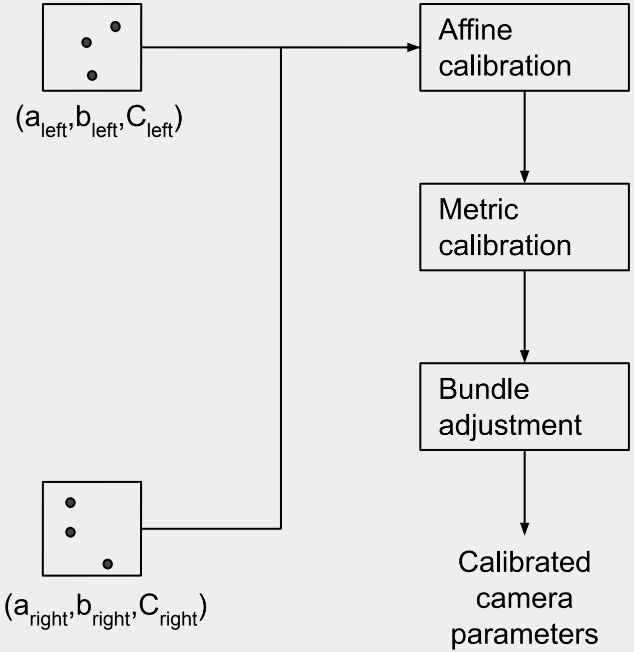
A. Stereo Infrared camera Calibration



Chessboard pattern based stereo camera calibration
(To get the extrinsic parameters of camera to perform depth estimation)

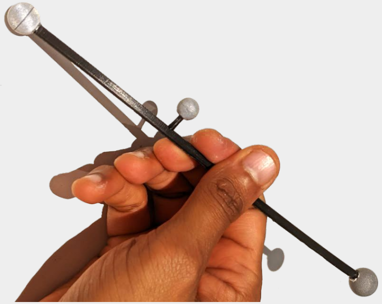
A. Automatic Calibration Procedure in RetroSphere

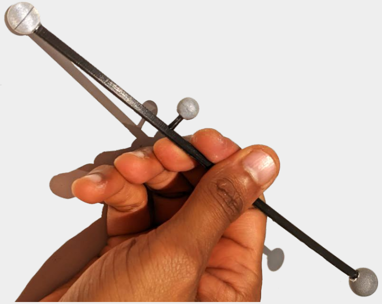
User randomly waves the stylus in mid air while wearing RetroSphere glasses (for 10-30 seconds).

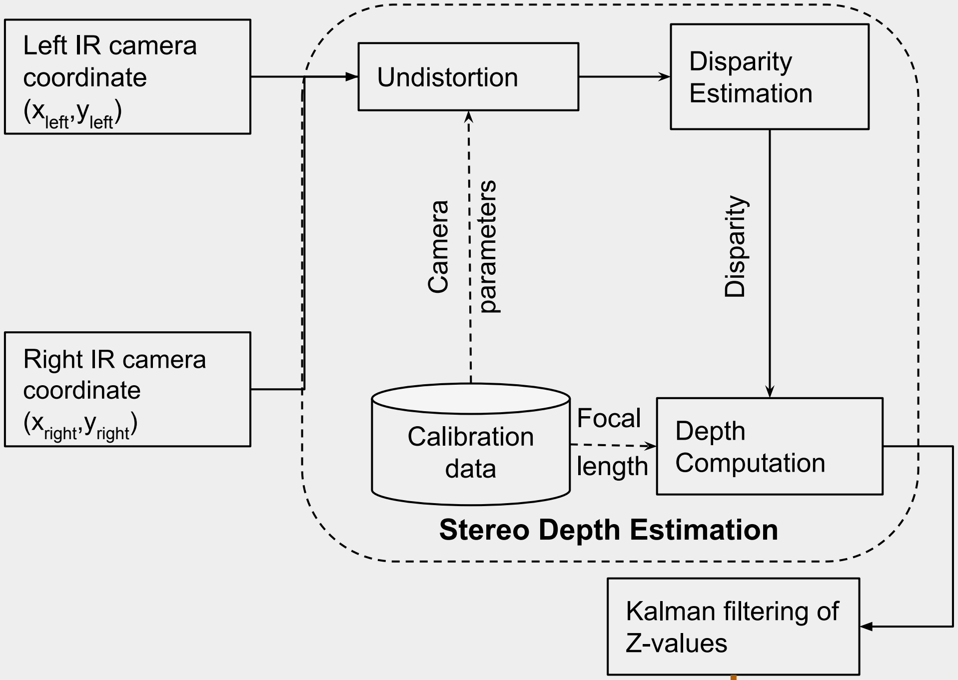


The calibration algorithm makes use of the geometry of the markers in our stylus to estimate the extrinsic parameters of the camera.

B. Stereo 3D depth estimation of each marker in the stylus







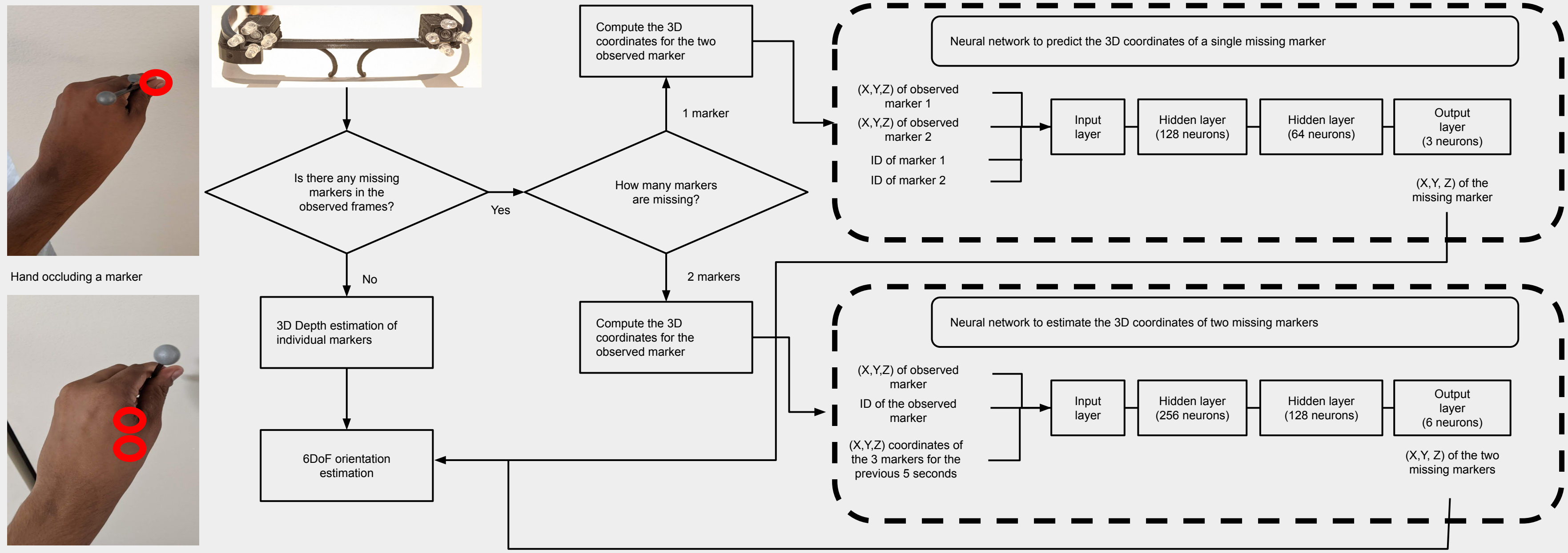
We now have the 3D coordinates of each marker in the stylus.

C. 6DoF estimation of each marker in the stylus

- For 6DoF orientation estimation, we need both the rotation and translation matrices.
- The reconstructed markers are then matched with their corresponding object markers using the size as well as the triangular geometry of the markers (A, B,C) in the RetroSphere stylus.
- Compute the rotation (R) and translation (t) matrices from the three marker positions(real-world coordinate frame) and compare them with the object markers (coordinate frame of the stylus) until

$$\|y_i - (\mathbf{R}x_i + \mathbf{t})\| < \text{tolerance}, \ \forall\, i \in \{1, 2, 3\}$$

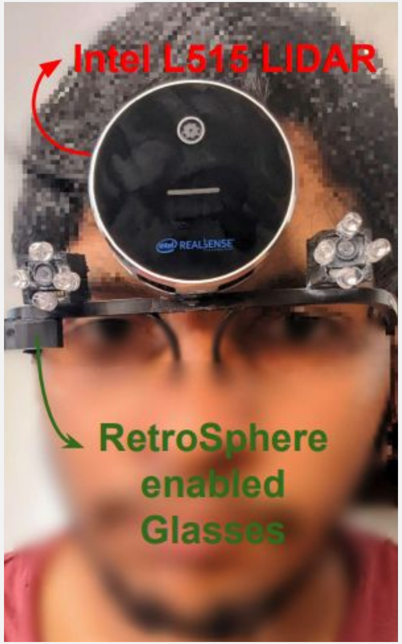
Neural Network-based Hand Occlusion Correction



Hand occluding two markers

Evaluations

User trials



- User trials with 20 participants (11 M, 9 F)
- Wore our AR glass mockup prototype
- Participants used our unity applications made for our AR glass mockup
  - 3 minutes on the 3D user interface application
  - 3 minutes on the drawing application
  - 4 minutes on the mid-air visualization application

Results

Tracking Accuracy

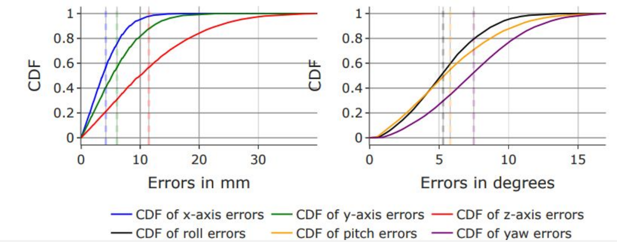
6DoF Parameters	Mean error	6DoF Parameters	Mean error
X (mm)	3.2	Pitch (deg)	4.65
Y (mm)	4.3	Yaw (deg)	6.95
Z (mm)	12	Roll (deg)	4.85
Position tracking error (mm)	18.5		
Orientation tracking error (deg)	5.85		

Depth sensing controllers	Average error
Kinect [33]	1% (4 cm)
Magic Leap [24]	1% (5 cm)
Intel RealSense D435 [7]	2 mm
POL360 [31]	0.691 cm
Oculus Quest [49]	3.5 mm
RetroSphere	**2.4% (~1.2 cm)**

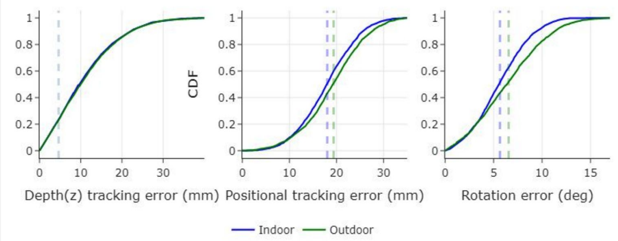
Results

Tracking Accuracy

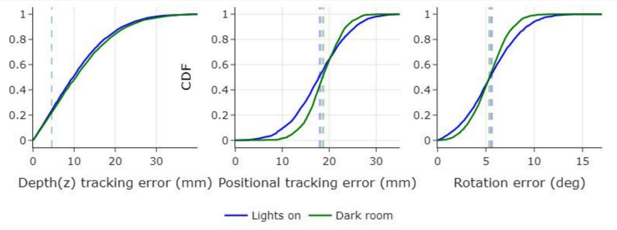
Hand Occlusion



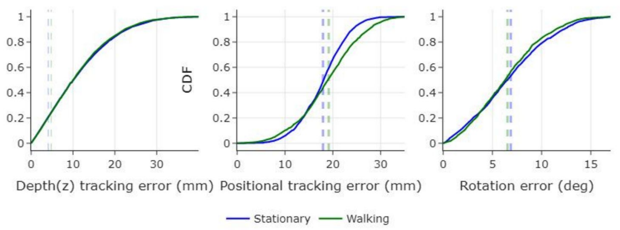
Environment (Indoor/Outdoor)



Lighting Conditions

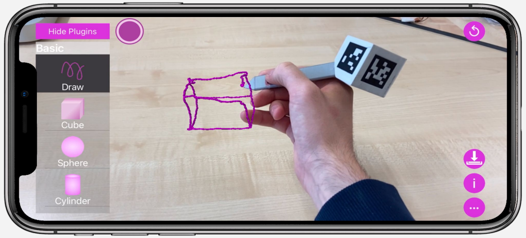


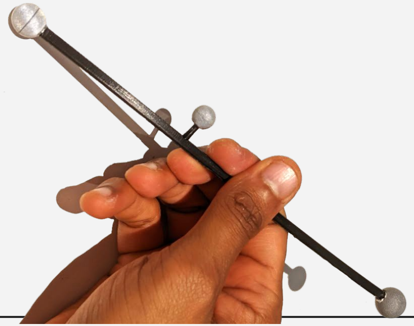
Motion (Stationary/Walking)



Results

Power and Latency





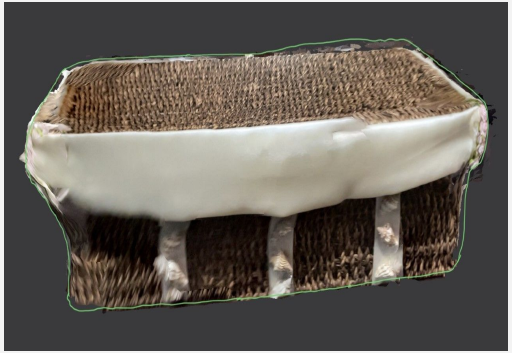
	Power Consumption (mW)	Latency (ms)
Dodecapen / ARPen	4200 - 5600	22 - 48
RetroSphere	**400**	**15**

Retrosphere offers *at least 10X power savings against ARPen* (the only passive AR controller tracking approach) and a *frame rate of 66 fps (15 ms)*.

Demonstrations with RetroSphere

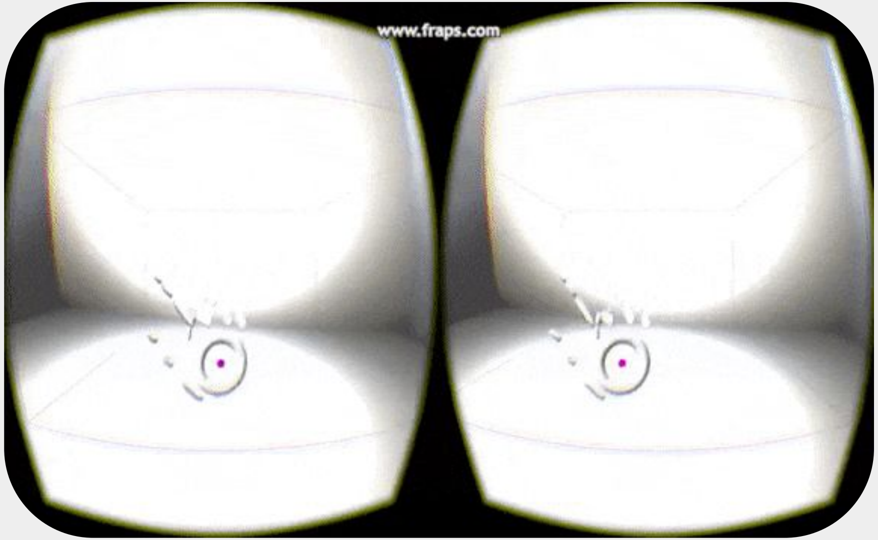
Demonstration

3D measurements

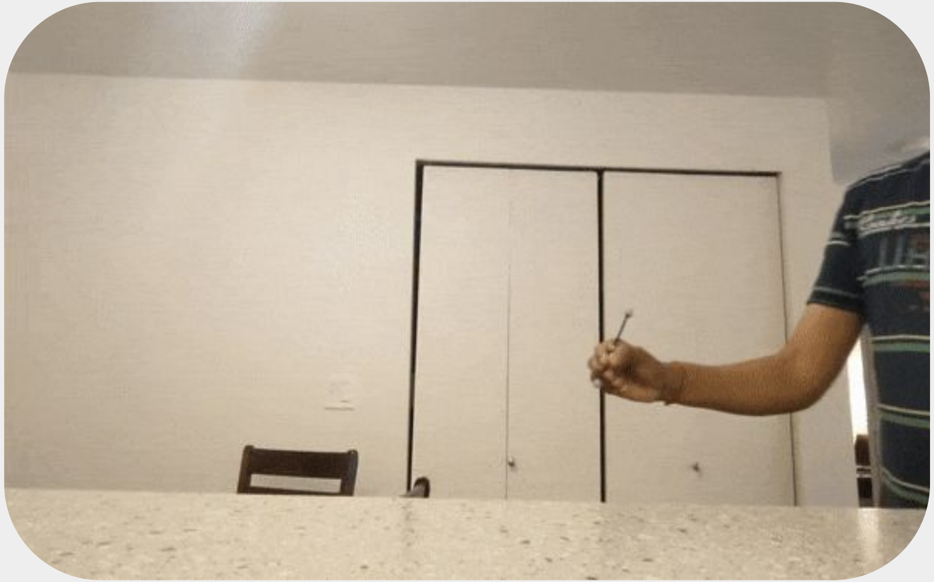


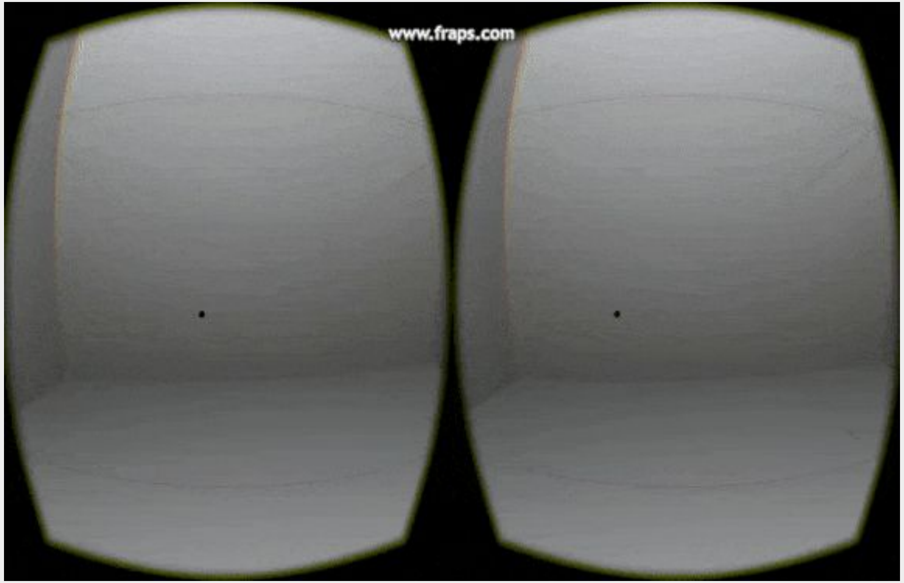
Demonstration

6DoF Mid-air Drawings



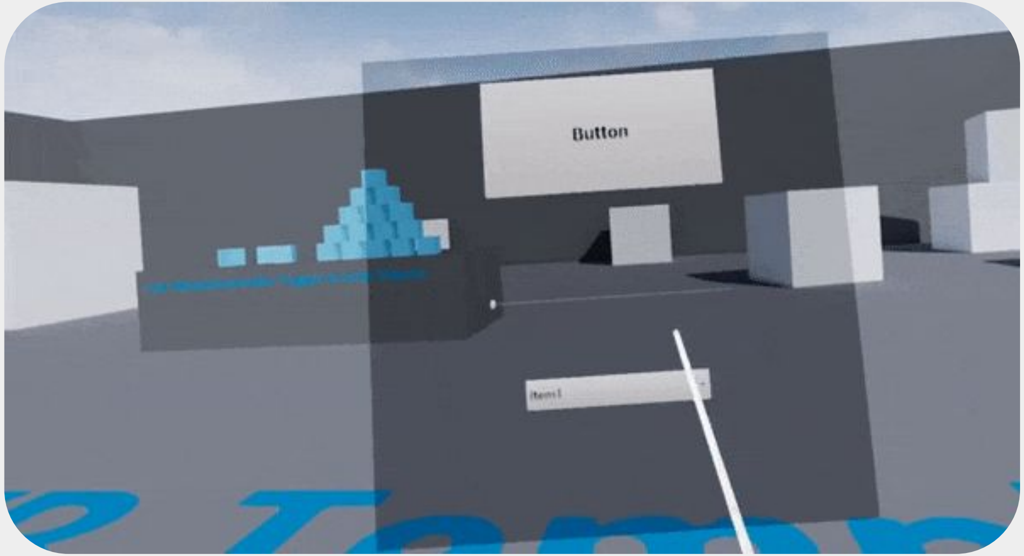
Demonstration
3D Drawings/Sculpting





Demonstration

VR User Interfaces

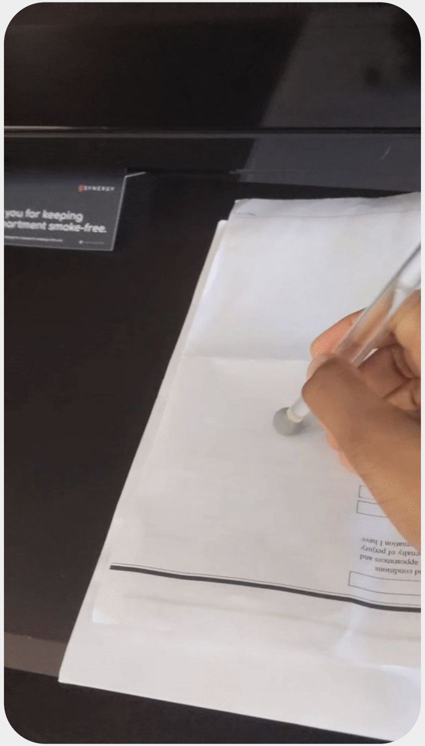


Use Cases

RetroPen

Use Cases

RetroPen - Working Mechanism



- Writing
- Erasing
- Pressure sensitivity
- Tilt sensitivity
- Battery-free/Passive

Use Cases

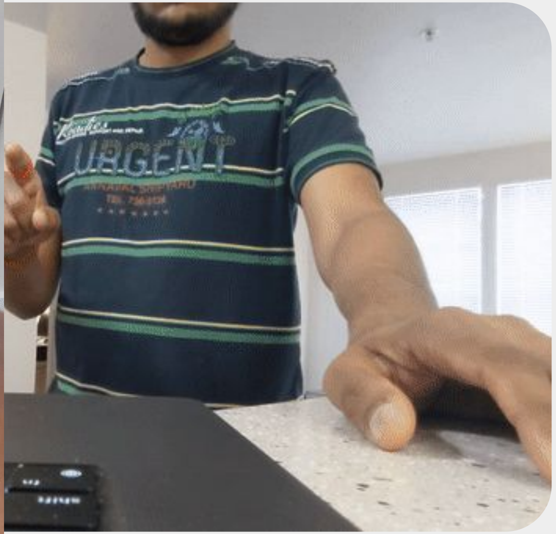
RetroRing

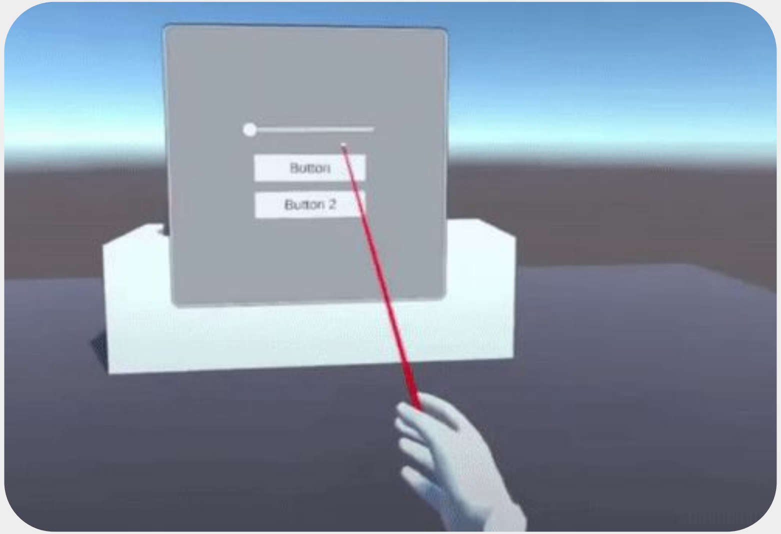
Retroreflective rings for thumb and index finger (each with a unique size).

Can be used to make gestures for 3D UI controls.

Use Cases

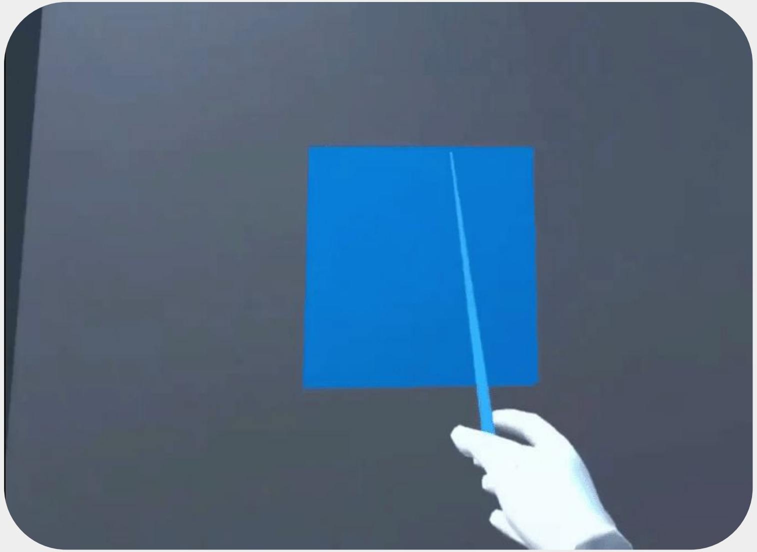
RetroPen - Single Finger Ring





Use Cases

RetroPen - Two Finger Rings



We hope that RetroSphere will allow researchers and practitioners to study and prototype spatial input on lightweight AR glasses more easily.


Q
&
A


THANK
YOU