Rethinking Orientation Estimation with Smartphone-equipped Ultra-wideband Chips

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What is orientation?

Orientation refers to the direction in which an object, or a person is faced at or pointed to.

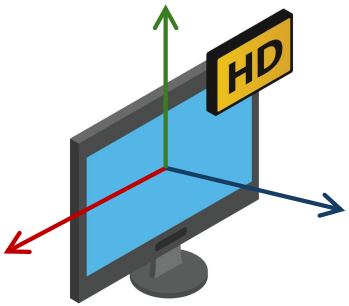
Bob faces at the TV.

Bob faces away from the TV.

Why is orientation important?

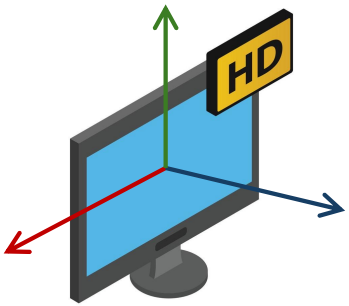
Orientation describes a distinct aspect of spatial awareness.

Why is orientation important?



Alice

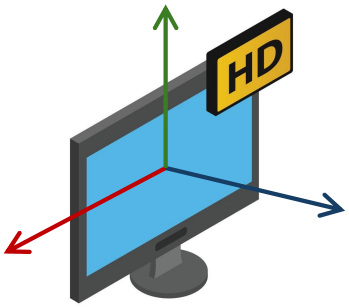
Why is orientation important?



Bob

Alice

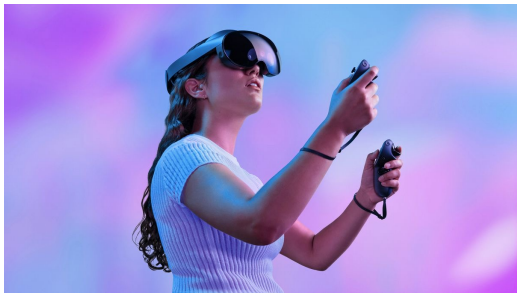
Why is orientation important?



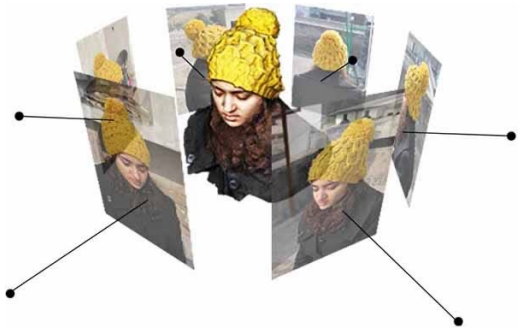
Bob and Alice are having a conversation.

Diverse applications with orientation

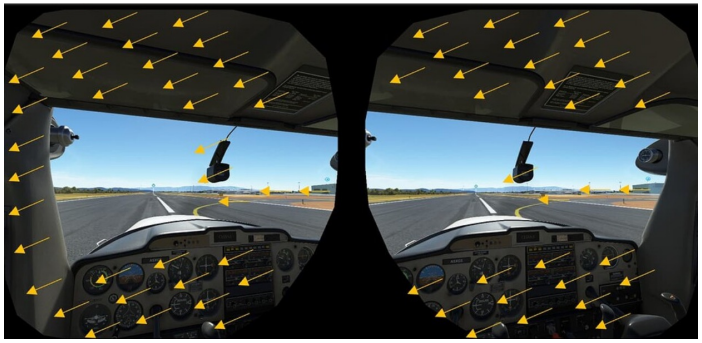
Phone Games



VR Interaction / Gesture Recognition

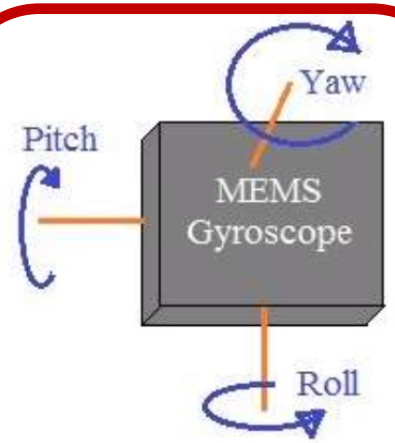


3D Reconstruction

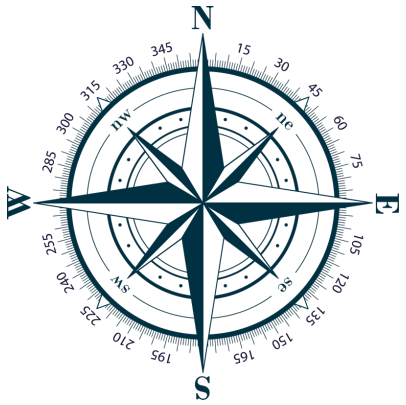


Orientation-based Reprojection

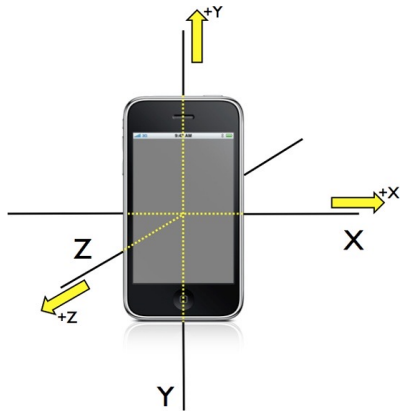
Prior Arts – Inertial Sensors



MEMS Gyroscope



Digital Compass



Accelerometer

Cumulative errors

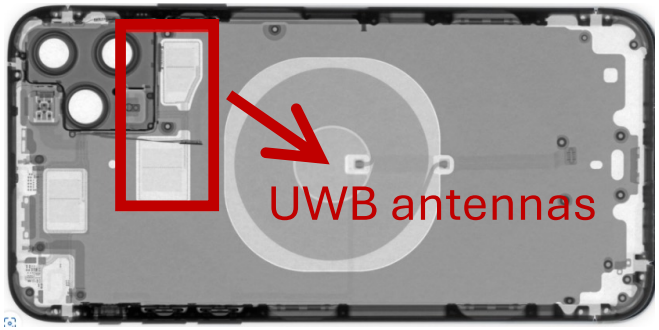
Prone to magnetic interference

Polluted by linear acceleration

New Opportunity

More and more consumer-level electronics are equipped with UWB modules.

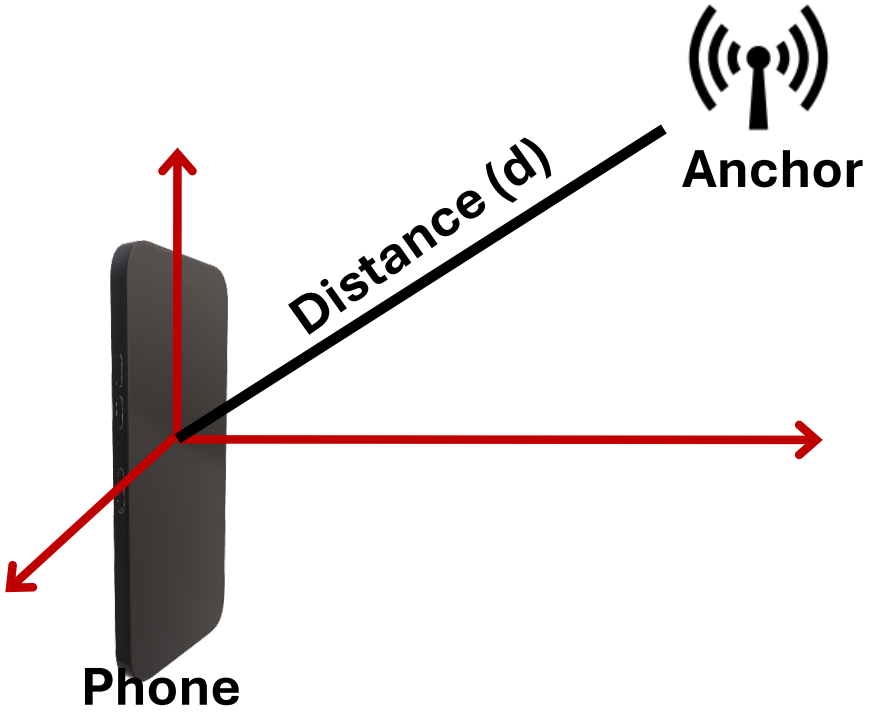
- Google → Pixel Pro series
- Apple → iPhone 11+, Apple Watch, Airtag
- Samsung → S21+
- XiaoMi → MIX4, Smart Speaker, etc
- BMW → Keyless entry



Airtags embedded with UWB modules

Challenges

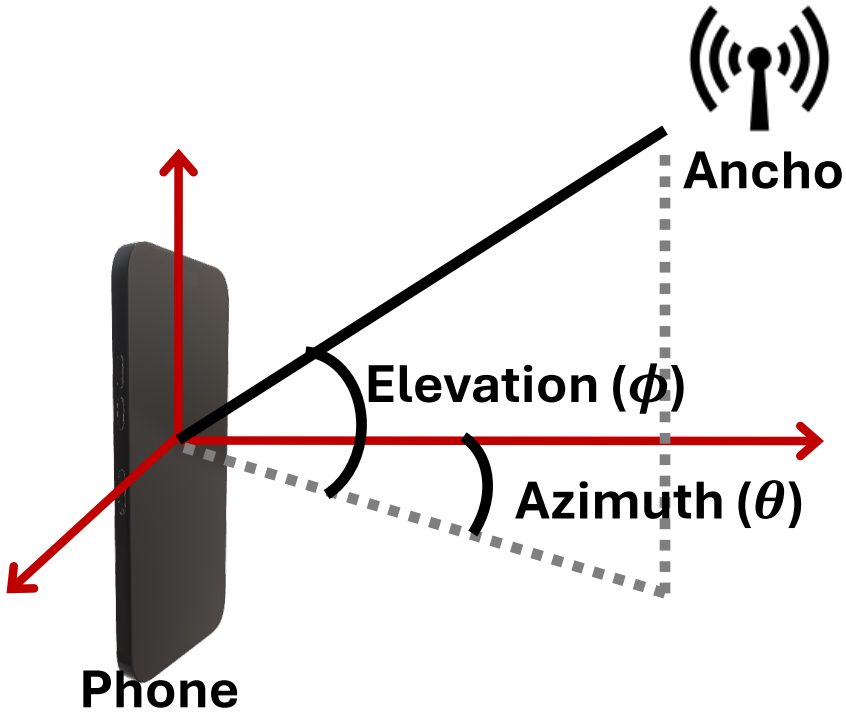
- No access to the low-level channel information from these UWB modules



UWB reported distance is too coarse for fine-grained orientation estimation.

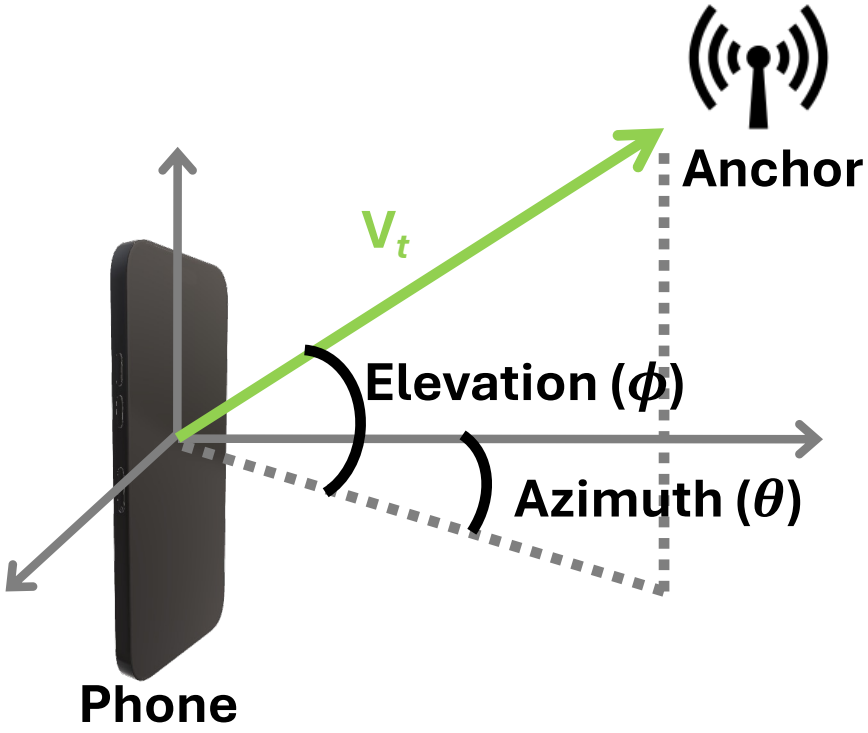
Challenges

- No access to the low-level channel information from these UWB modules



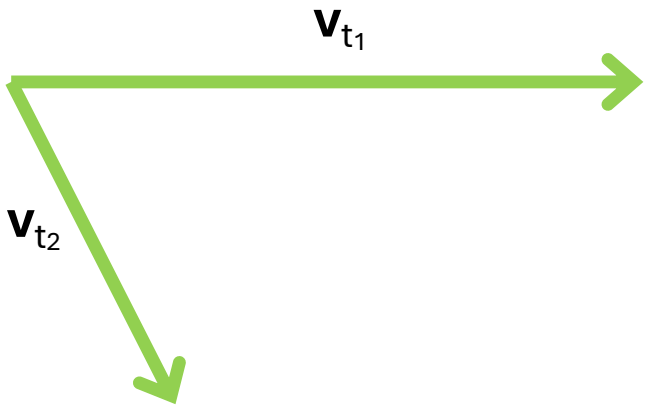
Can we use the high-level UWB angles for orientation estimation?

*From **UWB Angles** to **Orientation***

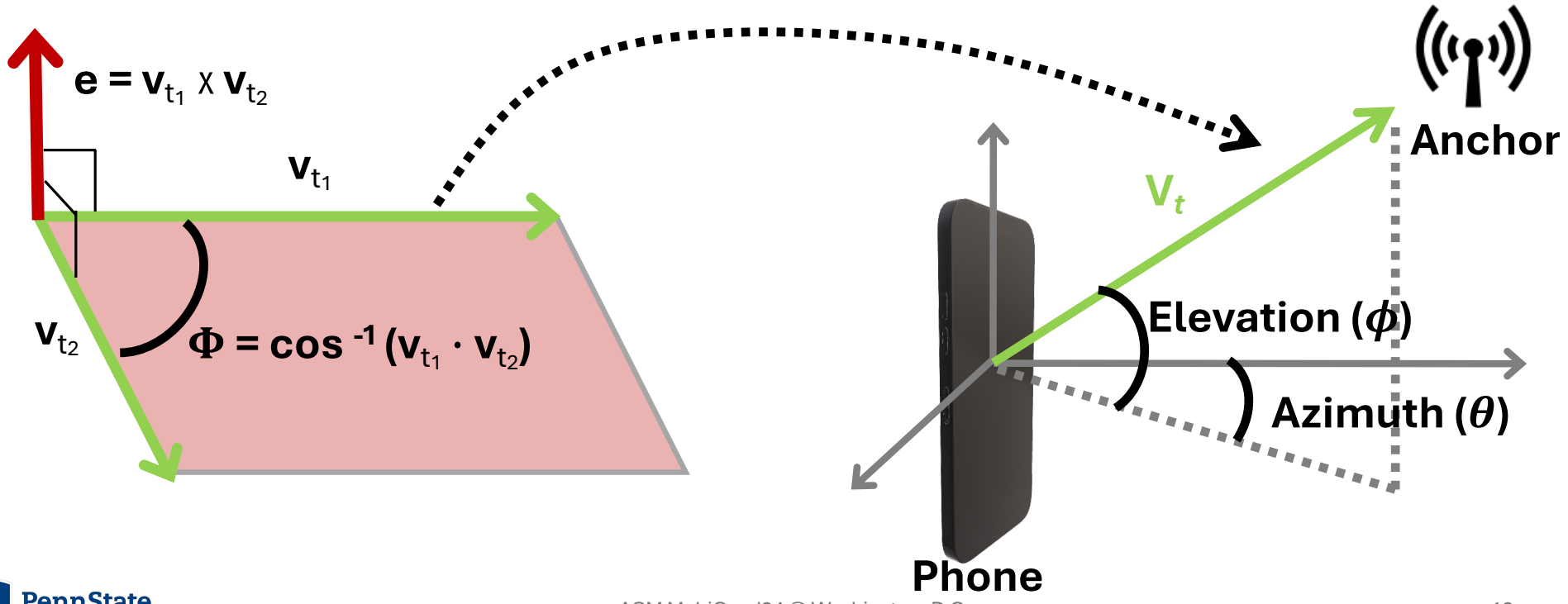


$$\mathbf{v}_t = [\cos(\phi)\cos(\theta), \cos(\phi)\sin(\theta), \sin(\phi)]$$

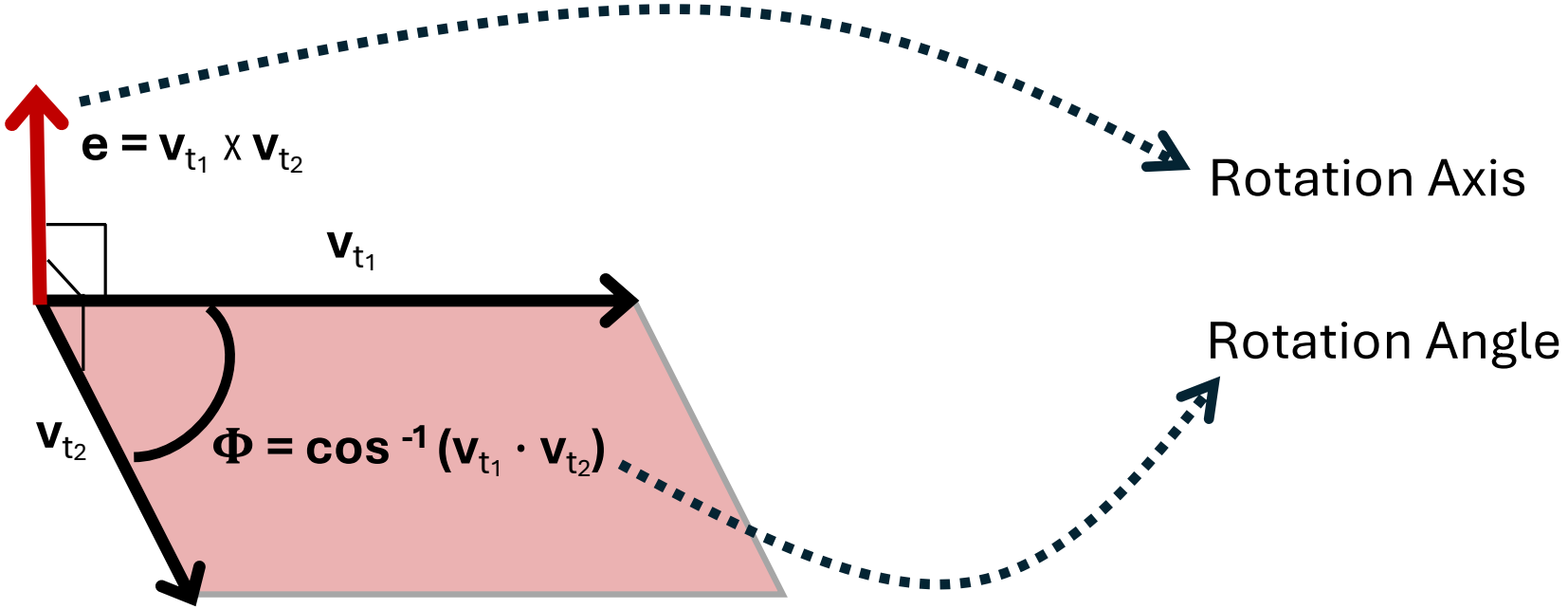
*From **UWB Angles** to **Orientation***



*From **UWB Angles** to **Orientation***

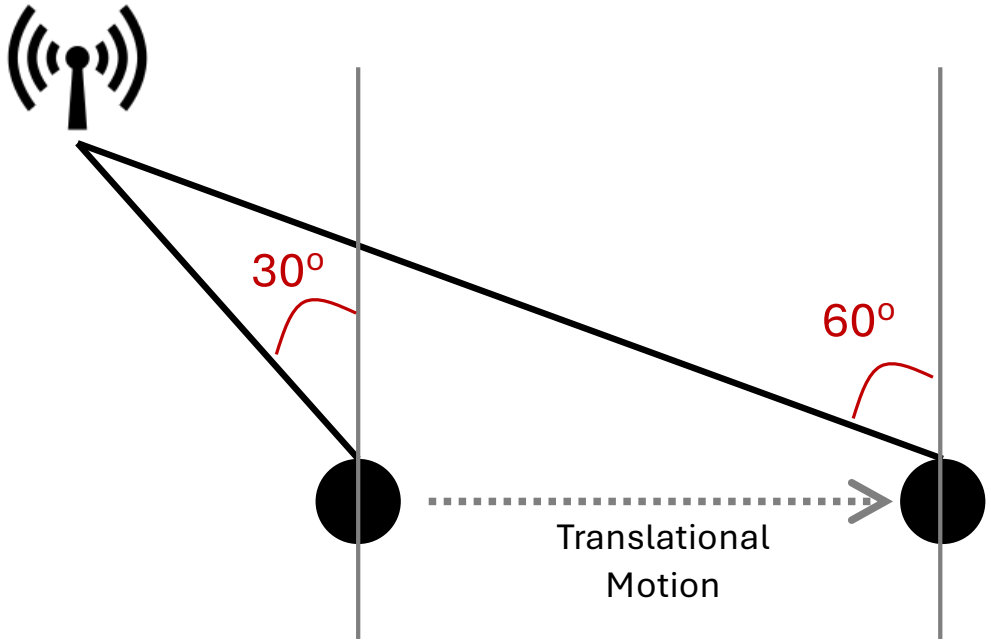


*From **UWB Angles** to **Orientation***



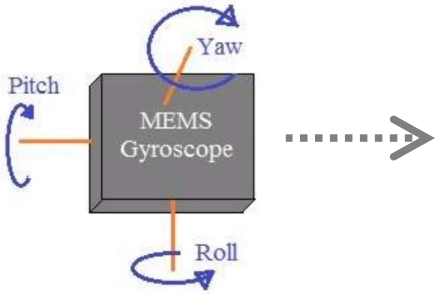
Challenges

- Translational motion will also incur the changes of UWB angles



Identifying *Translational Motion*

- Utilizing MEMS gyroscope to identify translational motion.



Calculate Orientation Difference

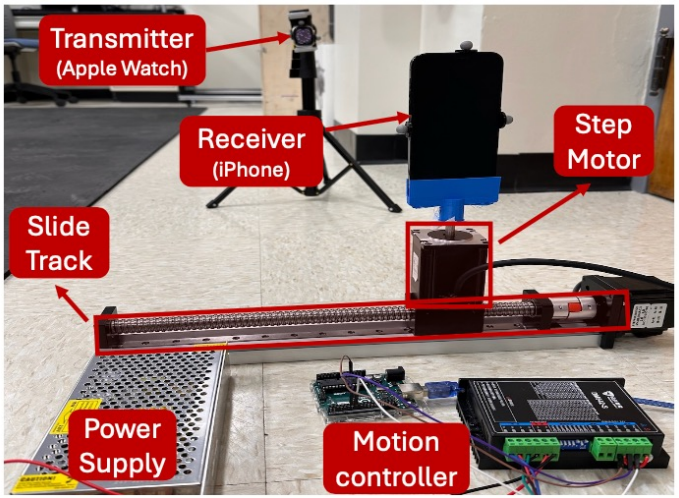
Not-interfered: UWB angles are good to calculate orientation.

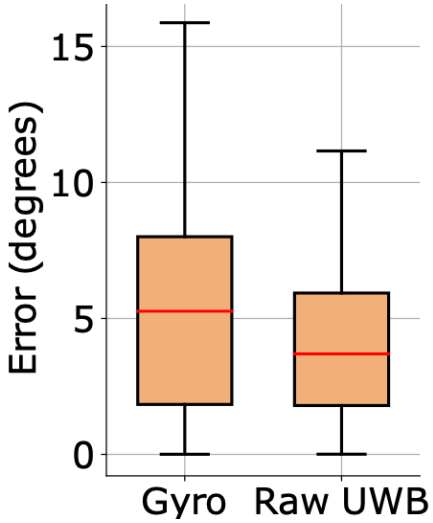
Interfered: UWB angles are interfered by translational motion.

*When **UWB estimates** are **not-interfered**...*

- When UWB estimates are not-interfered, we fuse those estimates with gyroscope estimates.

1 UWB based estimates are free of drifts.

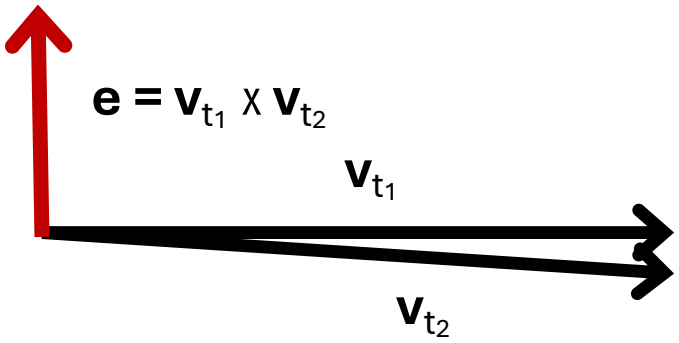


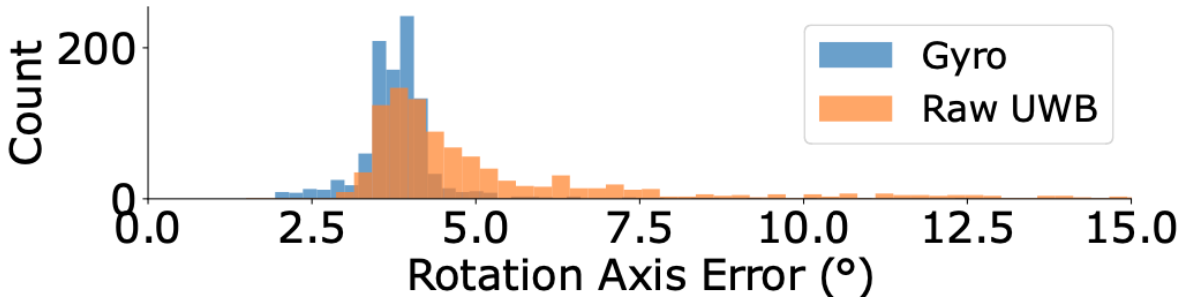


*When **UWB estimates** are **not-interfered**...*

- When UWB estimates are not-interfered, we fuse those estimates with gyroscope estimates.

2 UWB estimated rotation axis is prone to error.

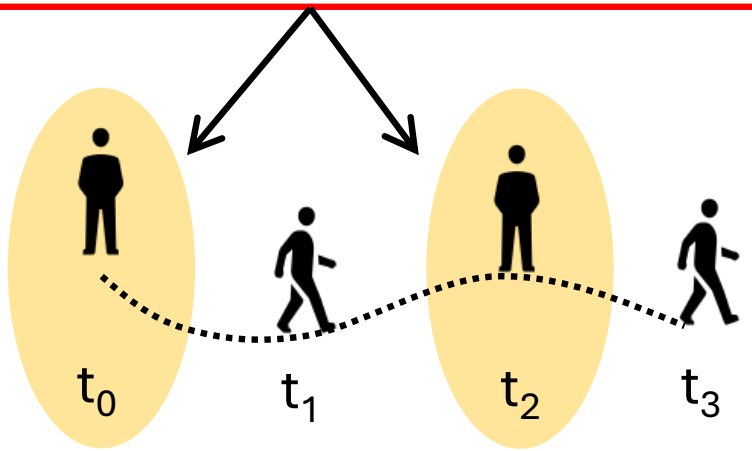




*When **UWB estimates** are **interfered**...*

- When UWB estimates are interfered, we replace those interfered estimates with gyroscope estimates.

Utilizing the frequent pauses (i.e., UWB angles are not interfered) to slow down drifting.



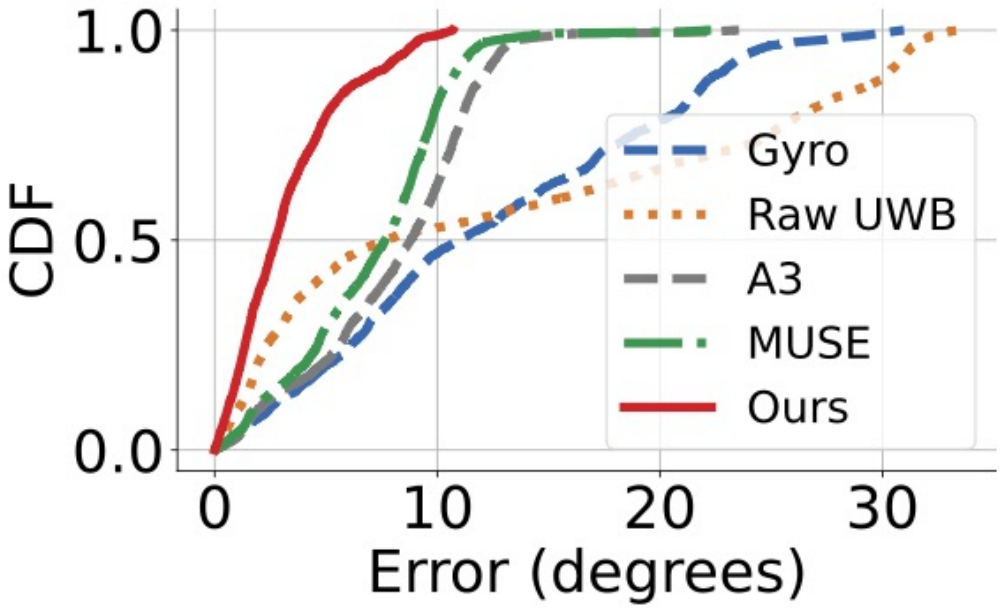
Evaluation

- UWB anchor that consistently transmits UWB pulses.
  - Apple Watch
- UWB receiver that receives the UWB signals to estimate UWB Rx's orientation
  - iPhone 12, Samsung S21 Ultra, Google Pixel 7 Pro
- Baselines:
  - Gyroscope
  - Raw UWB Angle
  - A^3
  - MUSE

Evaluation

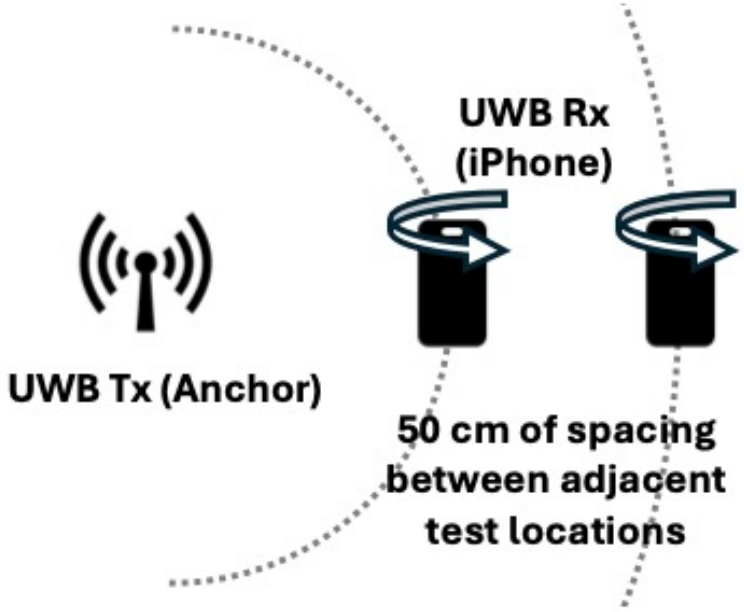

0.830 ft
azi: 41.113 deg
ele: 18.712 deg
Devices with Markers
Mounted on a roof rack
ViCON MotionCap System
IR Camera

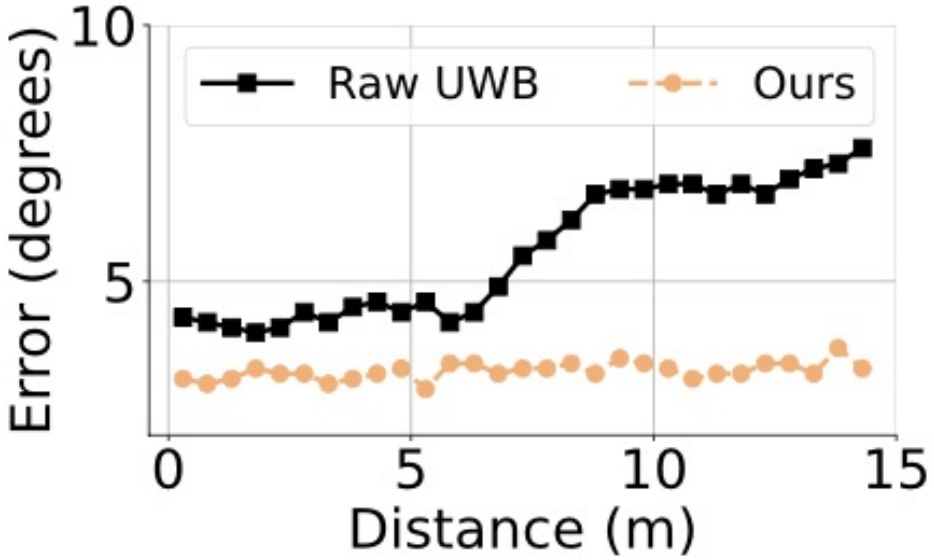
Under Free Motion



Our system has a median error of 2.7°

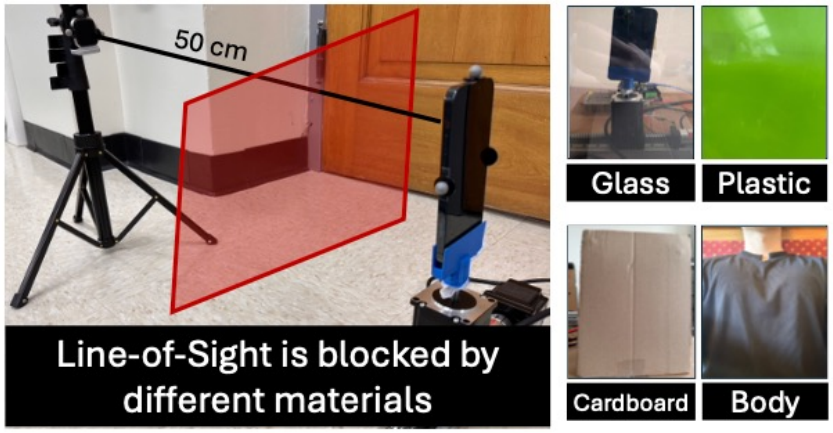
Effect of Distance between Anchor and Rx

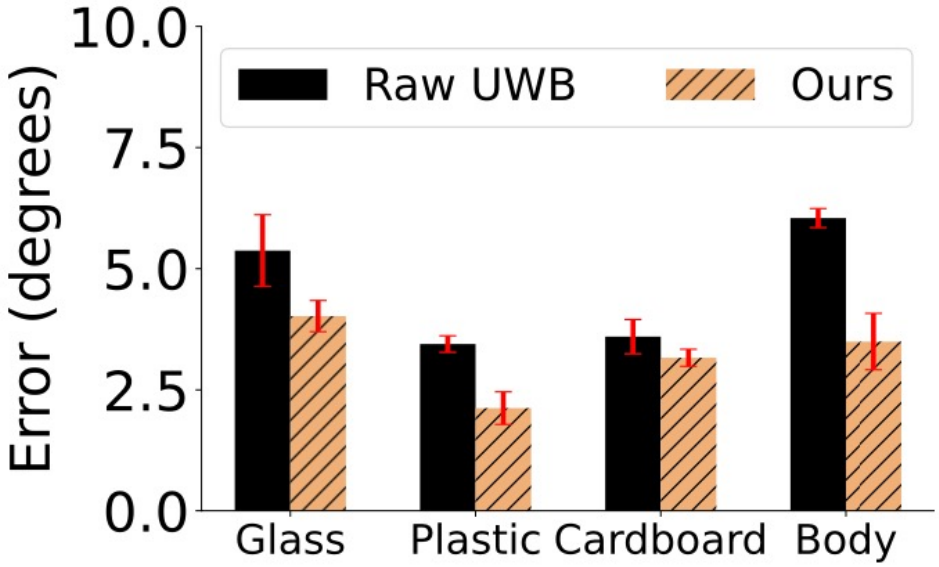




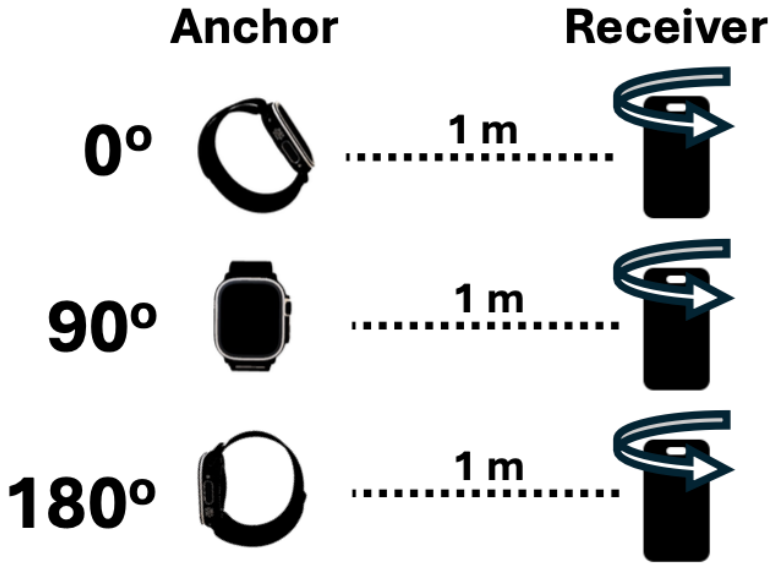
We have a large coverage

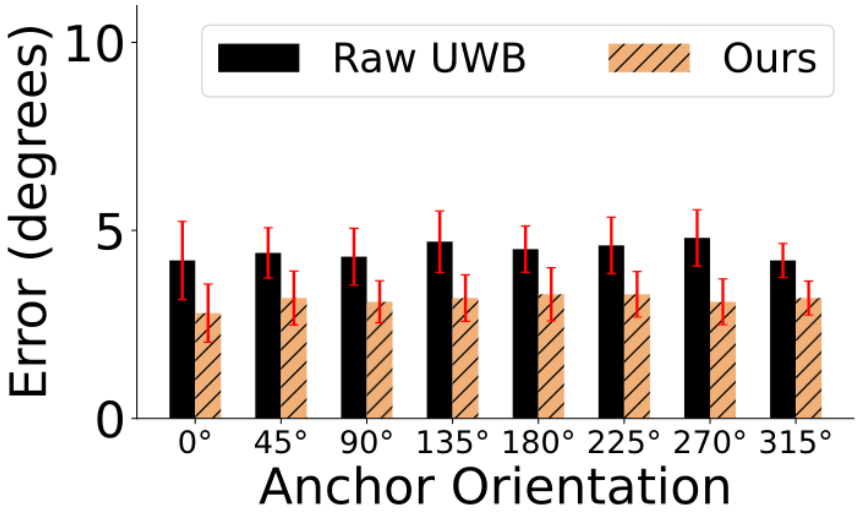
Effect of Non-line-of-sight





Effect of Anchor Orientation

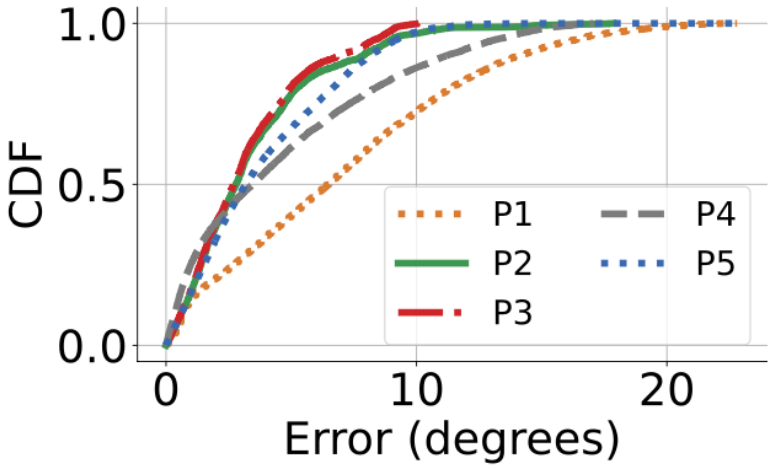




Our system works well under various anchor orientations, relaxing the placement of the anchor.

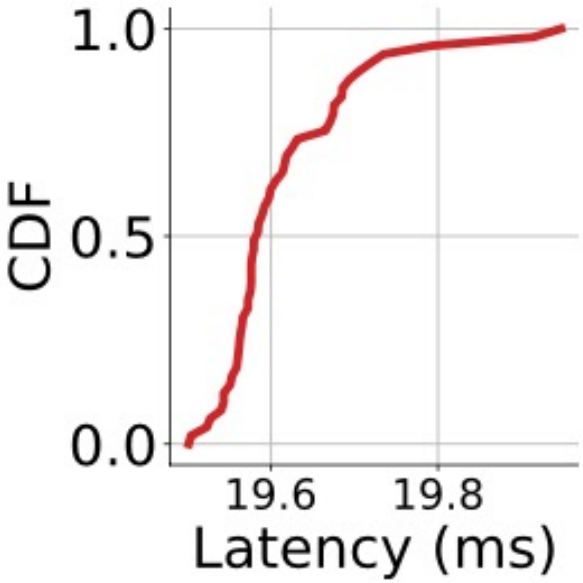
Performance over Various Platforms

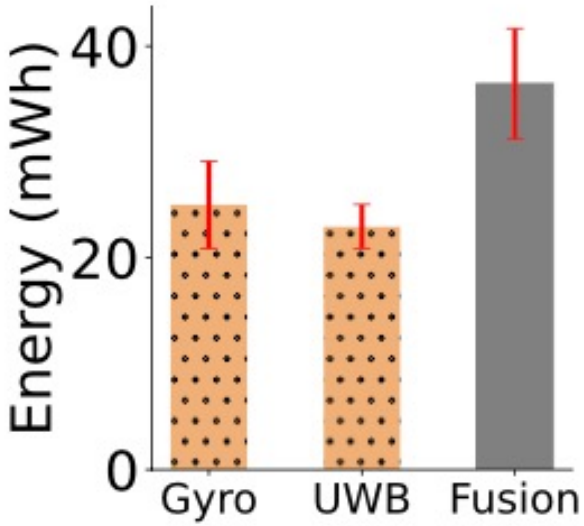
	Anchor	UWB Receiver
P1	AirTag	iPhone 12
P2	Apple Watch S6	iPhone 12 Pro
P3	iPhone 12	iPhone 12 Pro
P4	Samsung S21 Ultra	Google Pixel 7 Pro
P5	Google Pixel 7 Pro	Samsung S21 Ultra

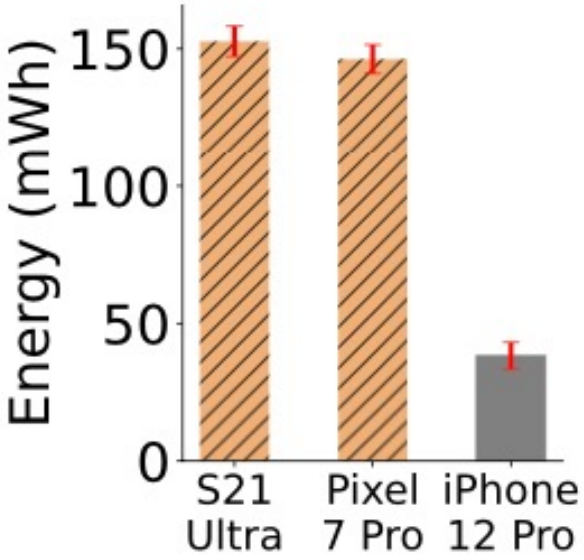


Universal across various device pairs.

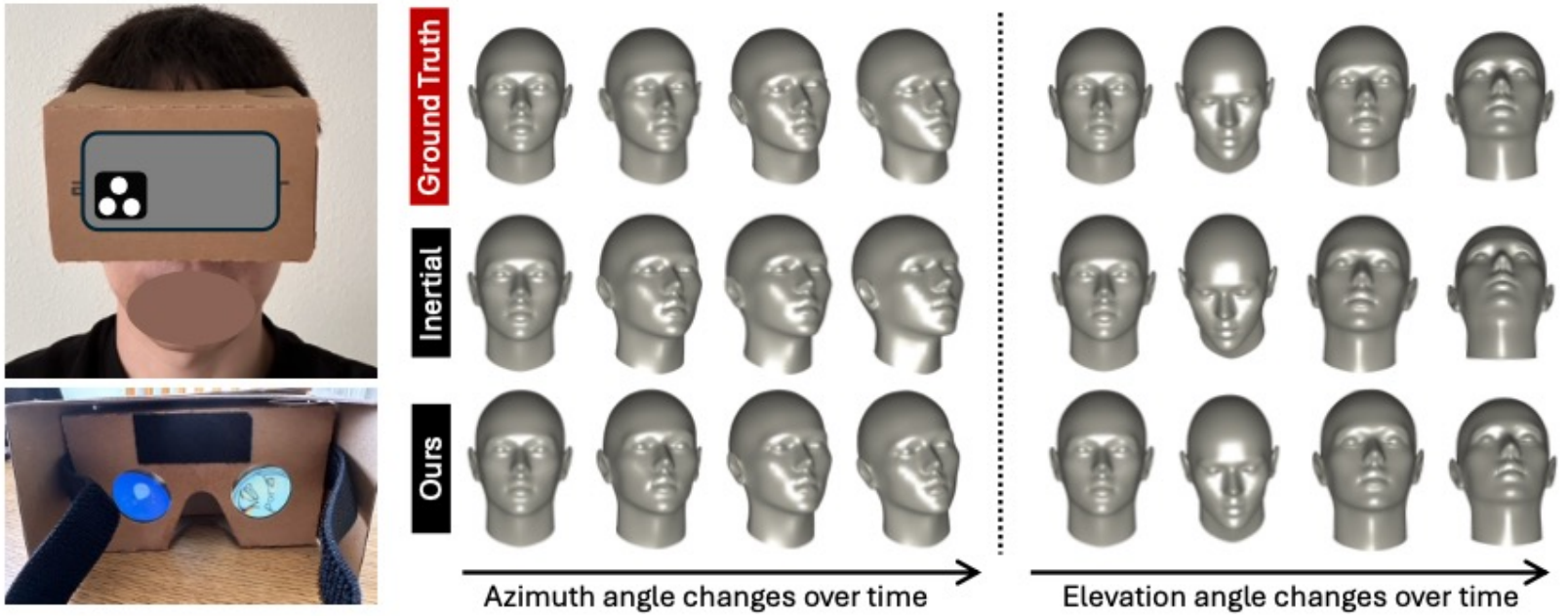
Latency and Energy Consumption







Real-world Application



Our system tracks head orientation well, making it suitable for VR applications by providing an immersive experience.

Conclusion

- Utilized **the exciting new opportunity** – more electronics now have UWB modules.
- Achieved fine-grained orientation estimation **without detailed phase/amplitude information** by utilizing characteristics of gyroscopes.
- Evaluation demonstrated the **efficacy and practicality** of our system, i.e., robust to signal blockage; large coverage; random anchor placement; accurate VR head orientation tracking.

Thank You