X-AR:
Augmented Reality with X-Ray Vision

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Battery-less
3 cent
Radio Frequency
IDentification
(RFID) Tags
signal
kinetics


RFID tagged items
inside boxes


RFID tagged items
inside boxes

Applications

Applications

Applications

X-AR

- First augmented reality headset that enables non line of sight perception
- It introduces novel techniques that bridges network wireless sensing with augmented reality for sensing and localization
- It can locate items with 9.8 cm accuracy in line-of-sight, non-line-of-sight, or fully occluded settings.

How does X-AR work?

We need an Antenna for RF sensing

Typical
RFID Reader

AR headset

Heavy and bulky

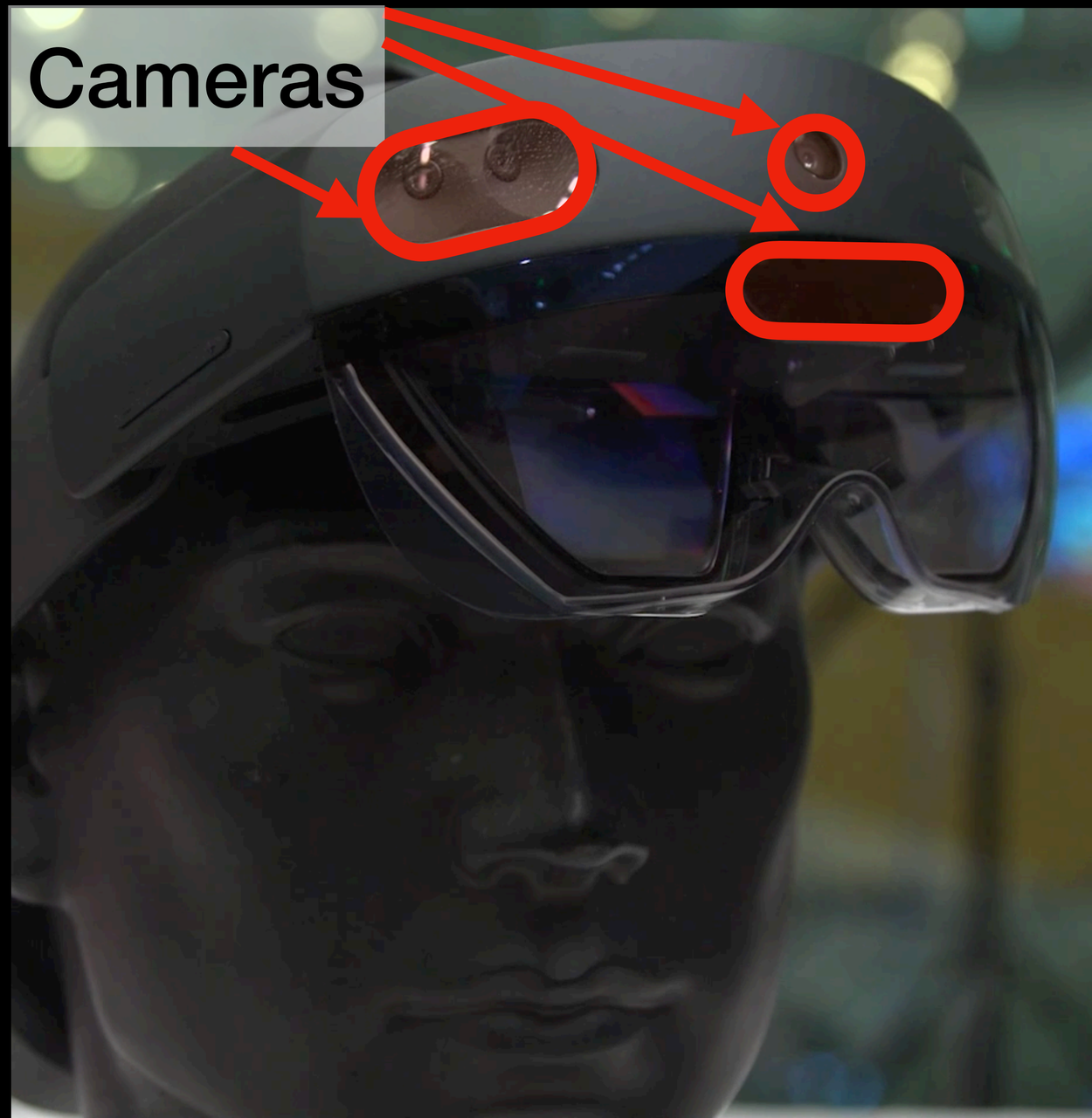
Difficult to move

We need an Antenna for RF sensing

- Wide Bandwidth
  - for accurate localization

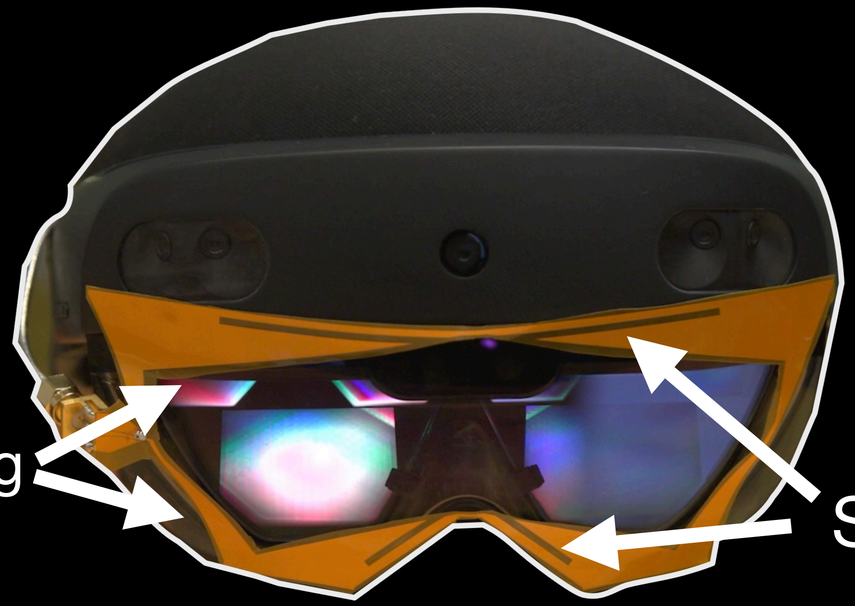
- Light Weight and Flexible
  - for easy mounting

- Matches Visor’s Shape
  - for not blocking cameras



We need an Antenna for RF sensing

Single Loop Antenna

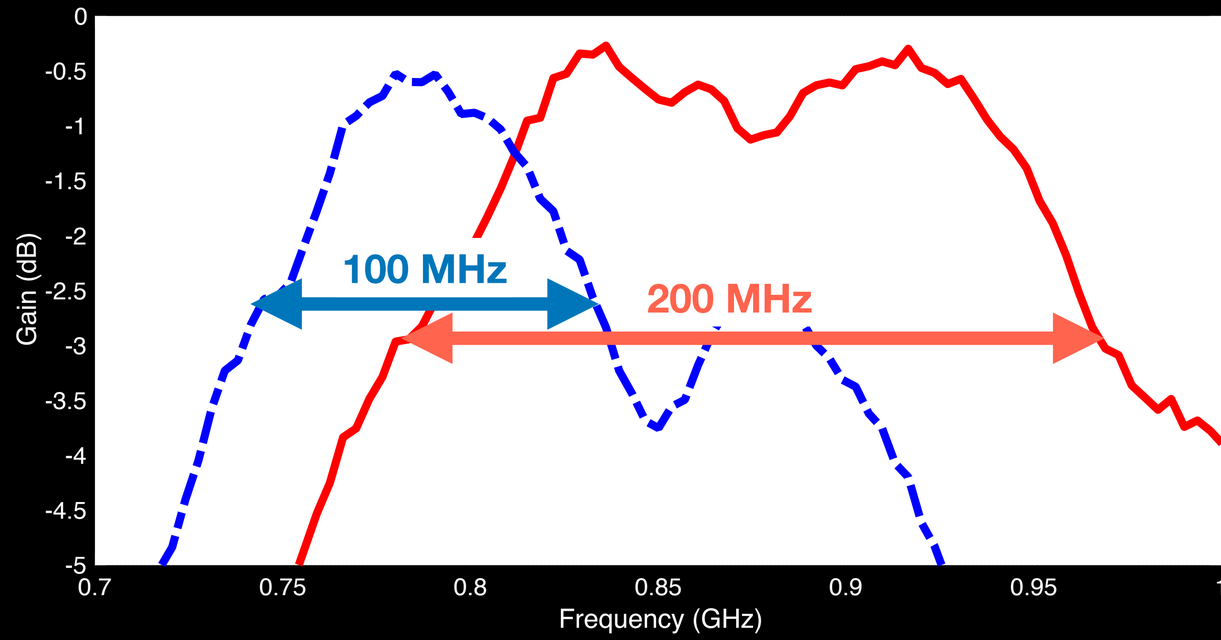


Wideband custom-designed Antenna

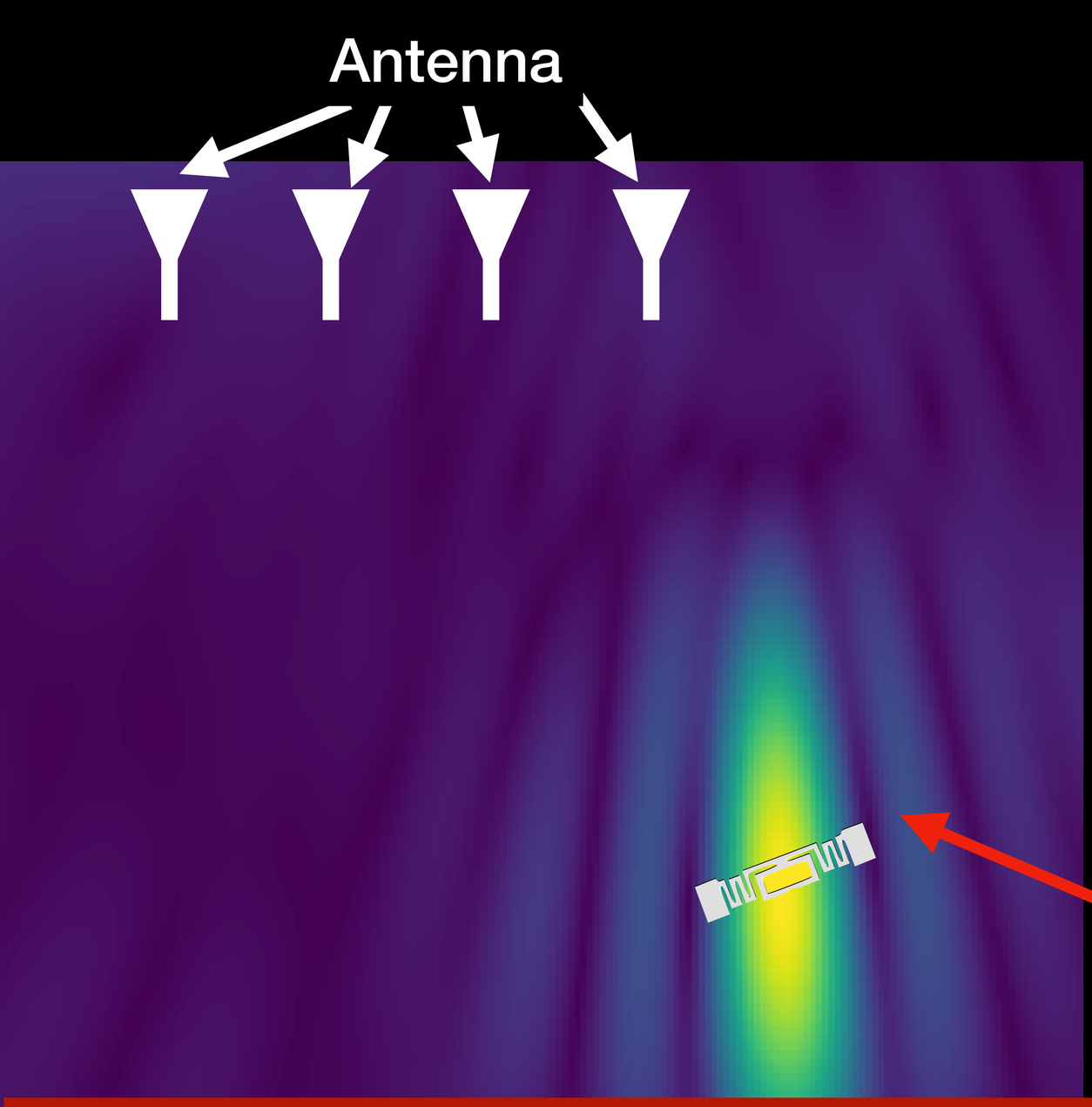
✓ Light Weight and Conformal

✓ Does not block Sensors

X Wide Bandwidth



✓ Wide Bandwidth (200 MHz)

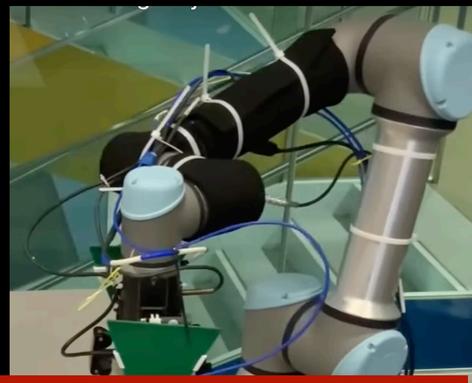


Synthetic Aperture Radar (SAR)

$$P(x,y,z) = \left|\left|\frac{1}{M}\frac{1}{N}\sum_{j=1}^{M}\sum_{i=1}^{N} h_{i,j} e^{\frac{4\pi d_i(x,y,z)}{\lambda_j}}\right|\right|$$

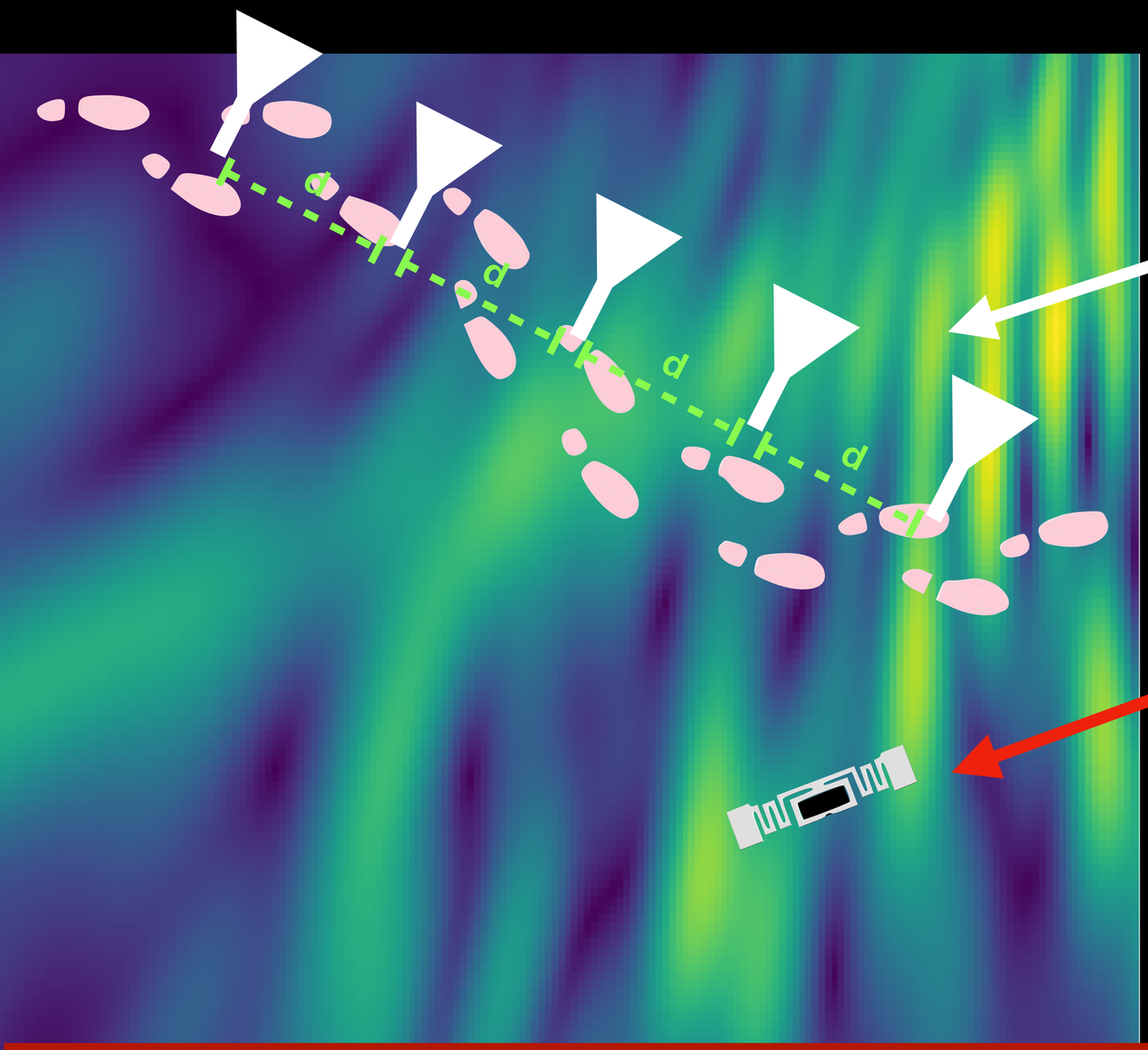
Robot and antenna movements are:

- on specific directions
- with constant speed



Human Natural Movements do not have constant speed or predictable direction.

Synthetic Aperture Radar



if we approximate antenna locations assuming constant velocity

Human Natural Movements

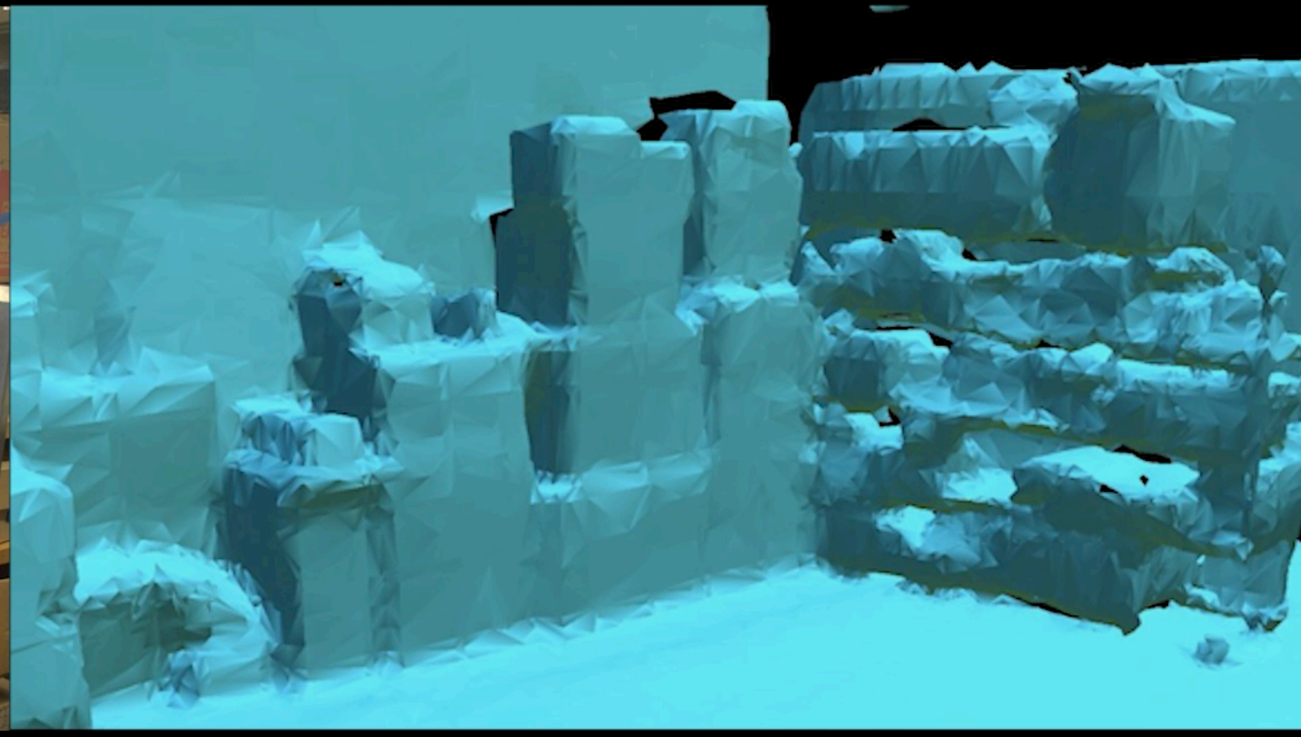
Target RFID

Inaccurate antenna location causes large errors in SAR localization

How can we accurately locate tags while using natural human motion?

Idea: Exploit AR headset sensors to track the human movements.

Real World



Virtual 3D map
using Cameras on AR headset

Idea: Exploit AR headset sensors to track the human movements.

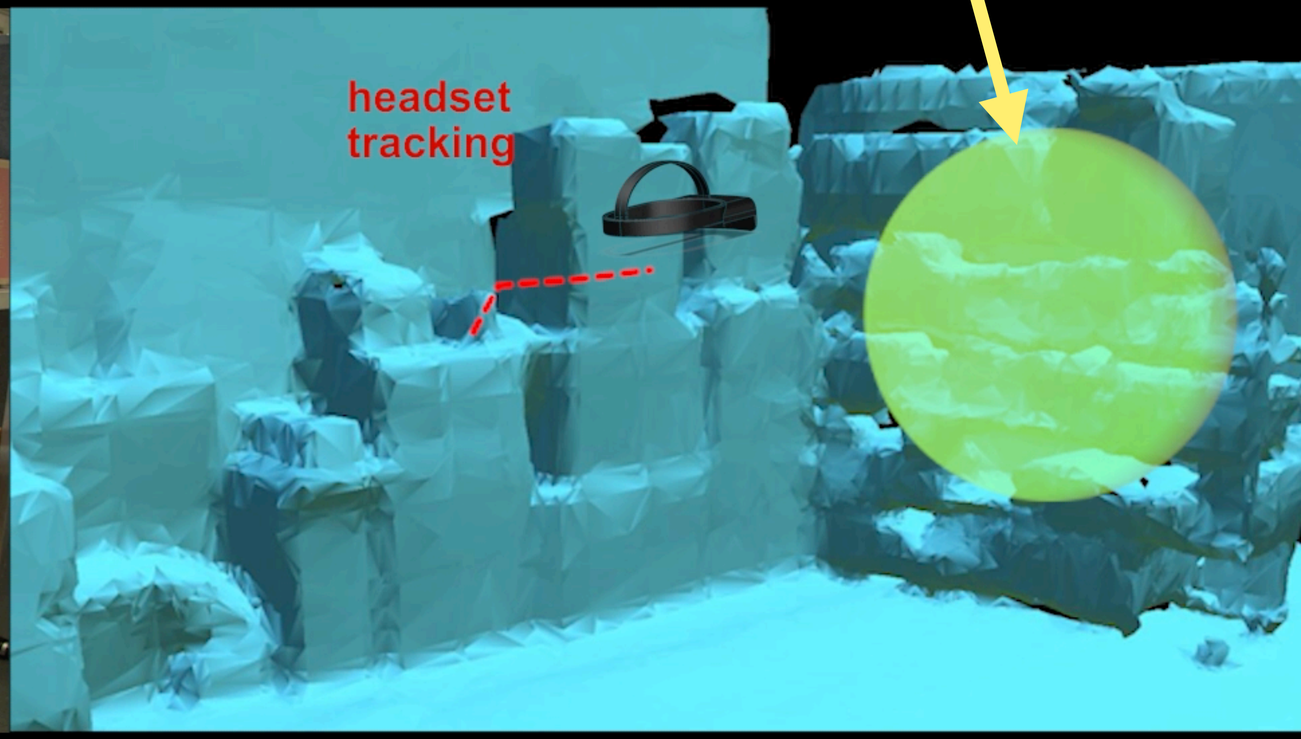
Track Headset location
through visual and inertial odometry

Real World

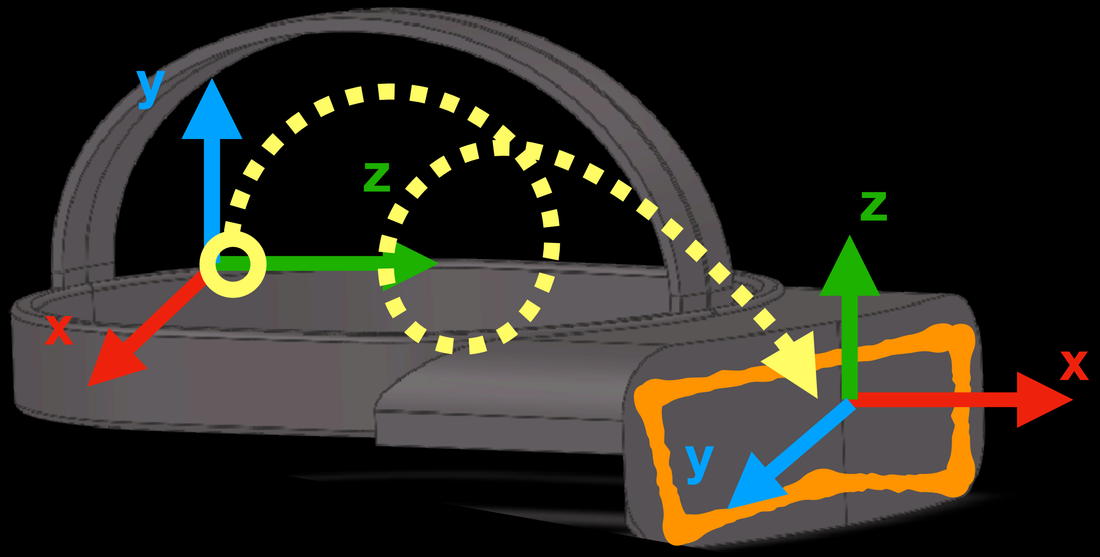
Virtual 3D map
using Cameras on AR headset

Idea: Exploit AR headset sensors to track the human movements.

Real World



Virtual 3D map
using Cameras on AR headset



Hololens Rotation

Hololens Position

Transformation

$$ {}^{W}P^{A} = {}^{W}R^{H} \times {}^{H}P^{A} + {}^{W}P^{H} $$

$$ P(x,y,z) = \left|\left| \frac{1}{M}\frac{1}{N} \sum_{j=1}^{M} \sum_{i=1}^{N} h_{i,j} e^{\frac{4\pi d_i(x,y,z)}{\lambda_j}} \right|\right| $$

User View

How can X-AR verify if user retrieves the target item?

How can X-AR verify if user retrieves the target item?

Solution 1:

- Use **Computer Vision** for object recognition

X Cannot distinguish between similar objects (e.g small or medium size shirt)

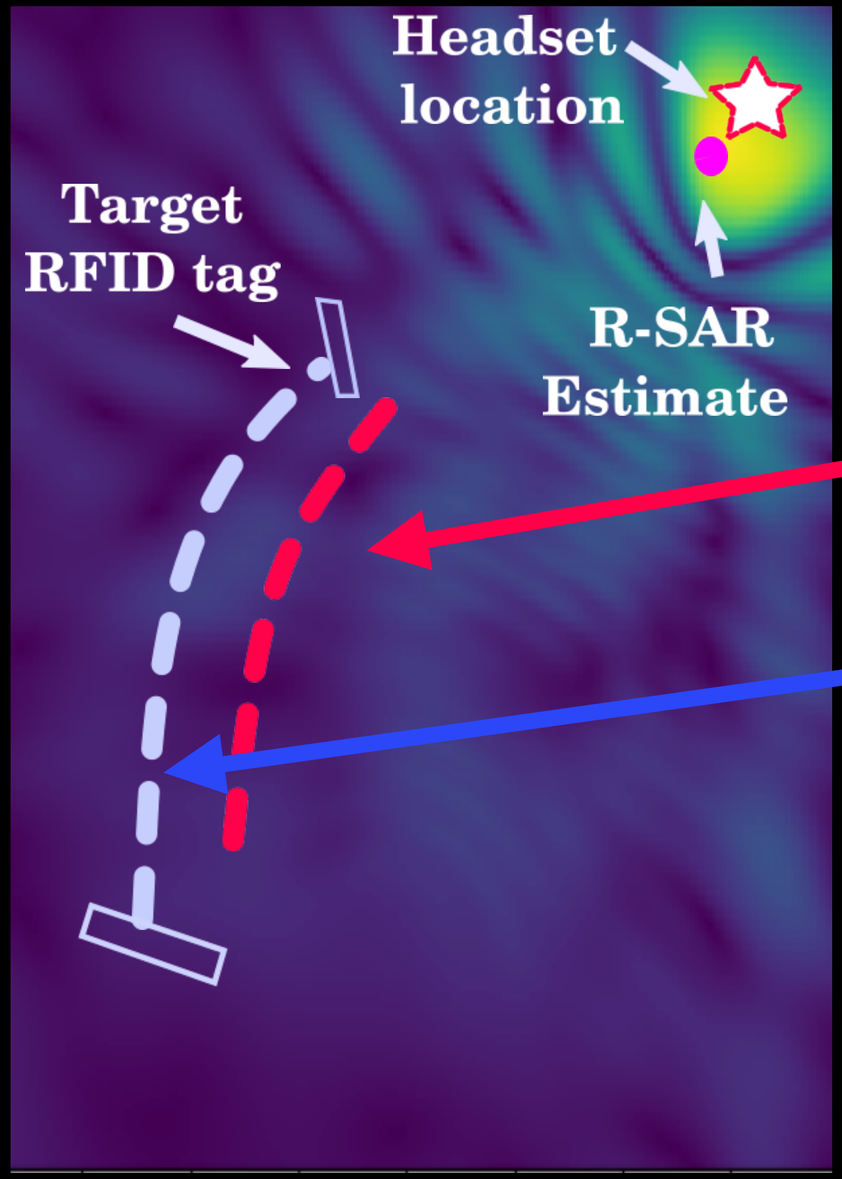
Solution 2:

- Use SAR to find RFID tag again

X Cannot locate a moving RFID tag

<u>Idea:</u> Use AR headset's hand tracking to create a reverse SAR with the RFID tag

How can X-AR verify if user retrieves the target item?

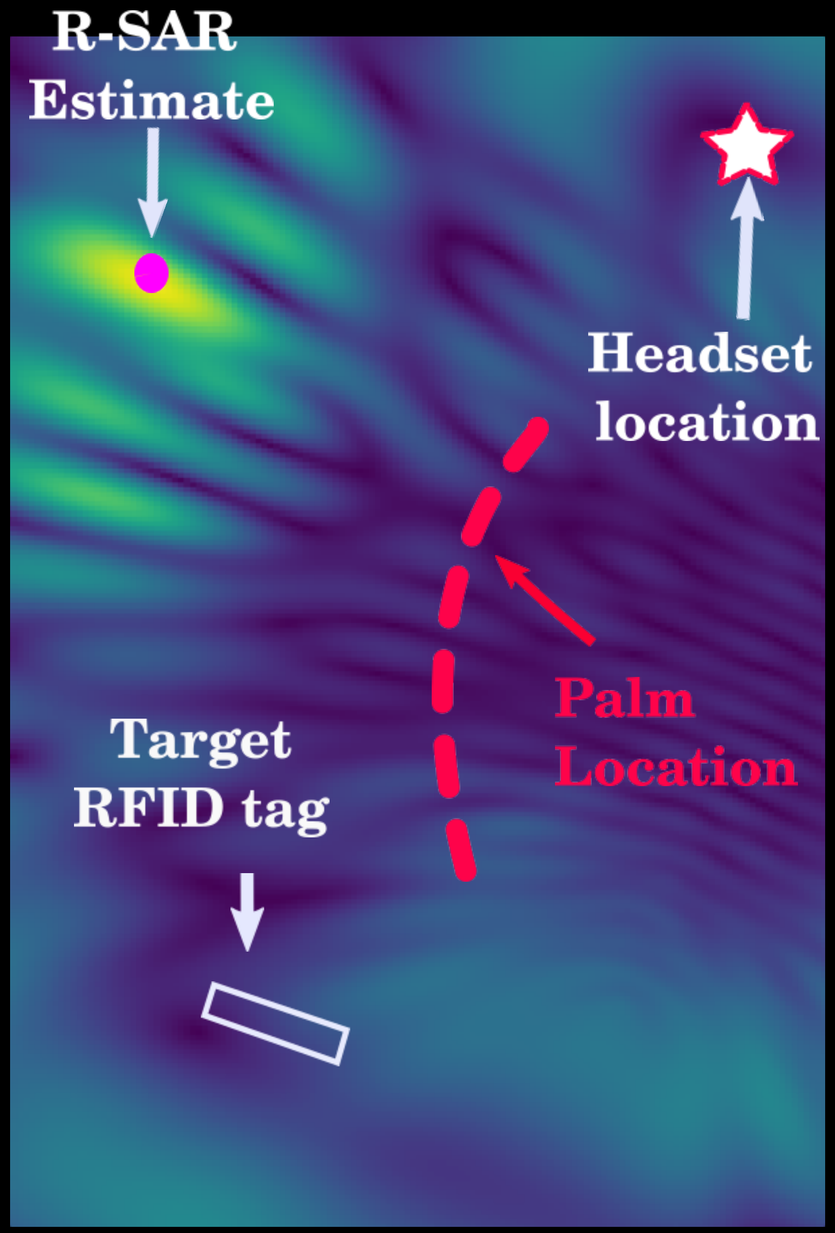


Target object is in-hand

Hand Trajectory

RFID tag Trajectory

How can X-AR verify if user retrieves the target item?



Target object is NOT in-hand

User view

Implementation

Edge Server (Ubuntu Machine):

- Receives information from Pi and Hololens
- Calculates SAR and R-SAR
- Sends commands to Hololens

HoloLens:

- Deployed our own App
- Self-Tracking, Hand-Tracking, Visualization

HoloLens

Wideband Antenna

on flexible (kapton) substrate
with 0.12 mm thickness
200 MHz BW, 920 MHz CF

BladeRF 2.0

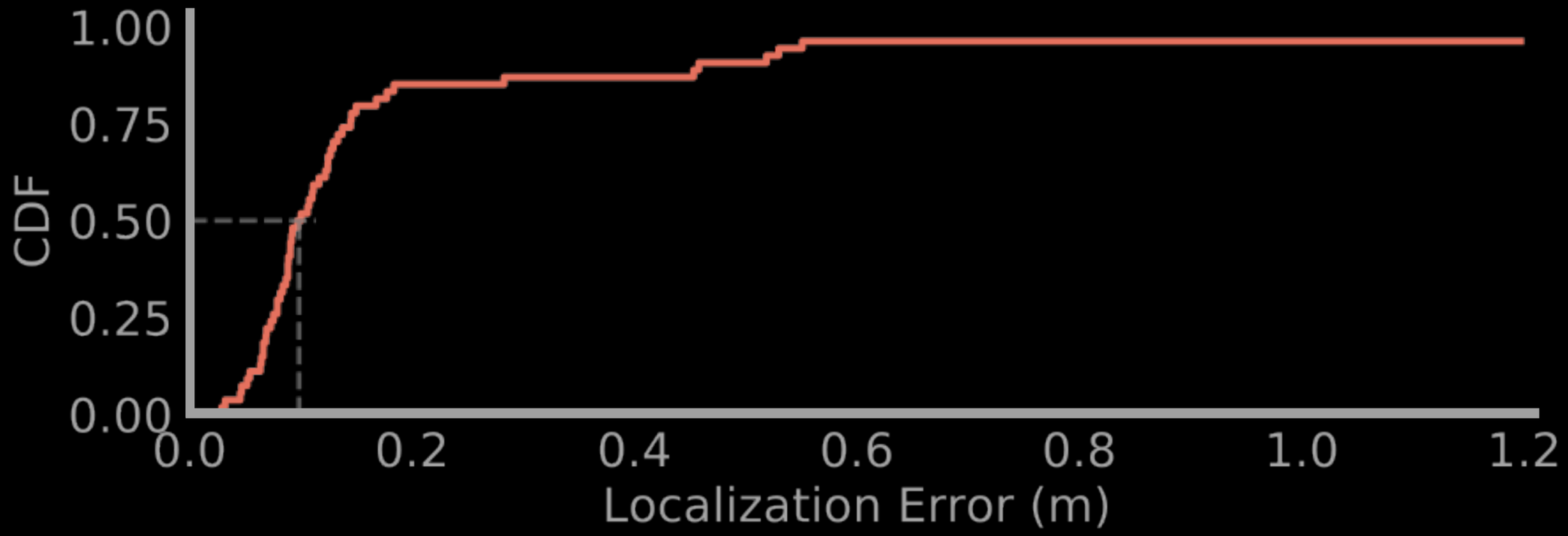
Software Defined Radio

Raspberry Pi

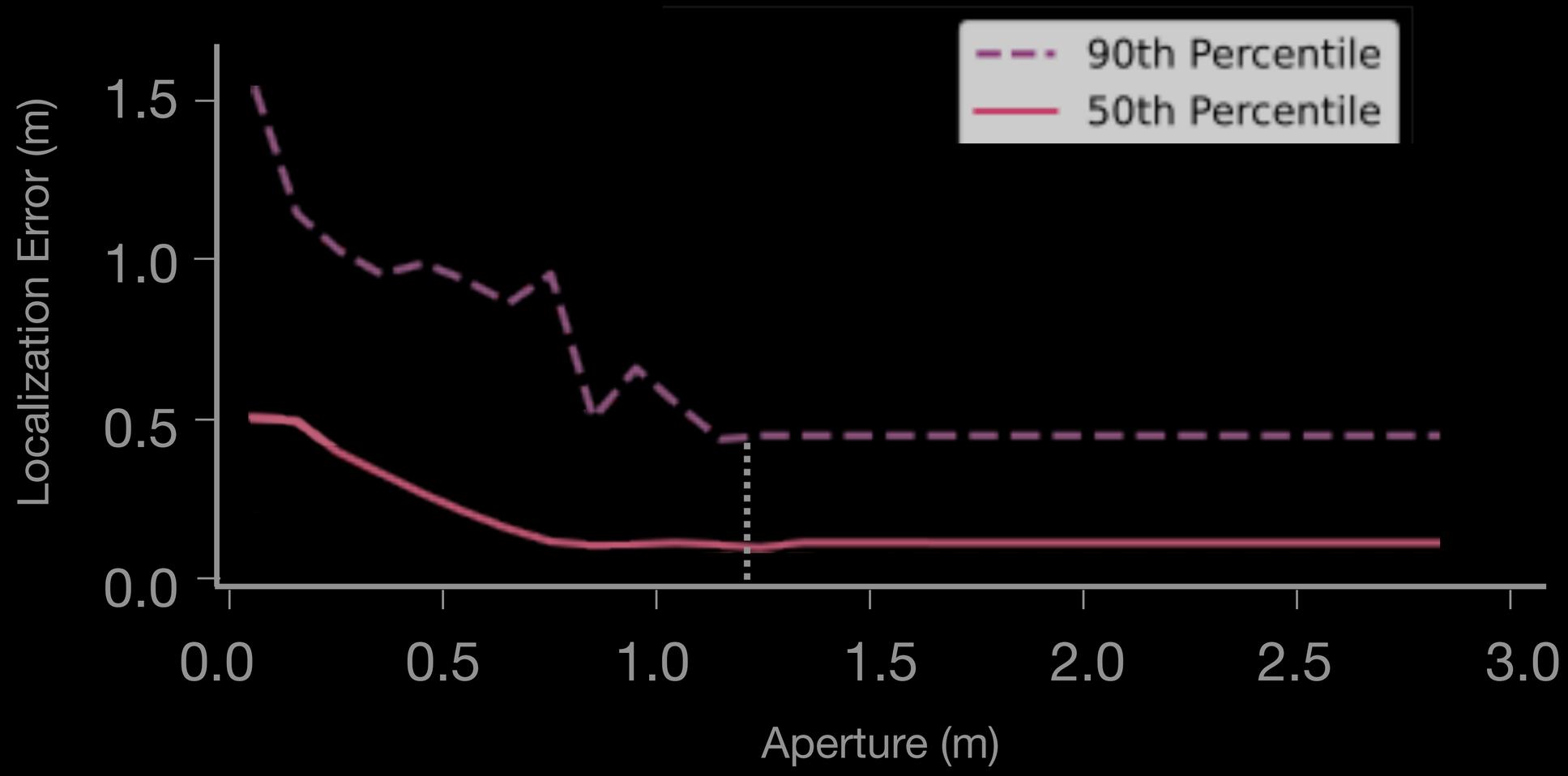
How accurate X-AR is in locating RFID tags?

User walks naturally toward a shelf or stack of boxes

Median Error is 9.8 cm



How much does the user need to walk?



How accurately X-AR can verify if target is in hand?

	Accuracy	
	Precision	**Recall**
RFID tagged Target in Line of sight	98%	100%
RFID tagged Target inside a box (NLOS)	100%	85.1%

Conclusion

X-AR:

First system to bridge network wireless sensing with augmented reality for sensing and localization

- Introduces techniques for:
  - AR-conformal, flexible and wideband Antenna
  - AR-Based SAR
  - In-hand Verification

- Opens up new applications in manufacturing, retail, warehousing, and smart homes

xar.media.mit.edu