TagScan: Simultaneous Target Imaging and Material Identification with Commodity RFID Devices

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Many applications are enabled by **passive** sensing

Gesture recognition

Virtual Reality

Elderly Monitoring

Intruder Detection

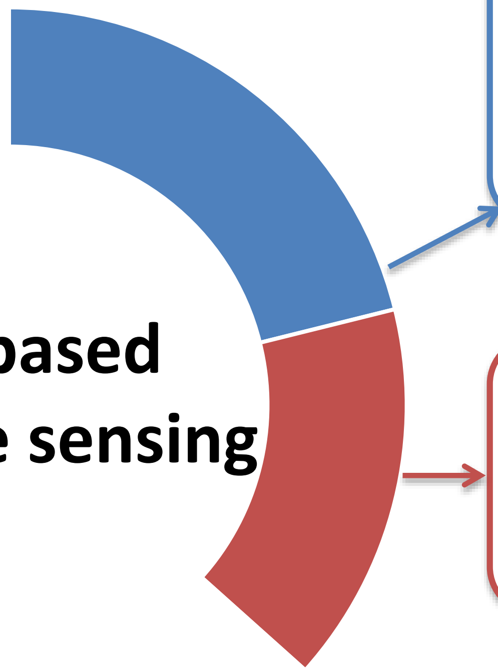
Current Solutions

Localization

[RTI’10], [VRTI’12], [Nuzzer’13], [WiTrack’14], [mTrack'15], [LiFS'16],…

RF-based passive sensing

Current Solutions



RF-based passive sensing

Localization

[RTI’10], [VRTI’12], [Nuzzer’13], [WiTrack’14], [mTrack'15], [LiFS'16],…

Motion tracking

[Wi-Vi ’13], [WiFall’14], [AllSee’14], [WiKey'15], [CARM’15], [EQ-Radio'16].

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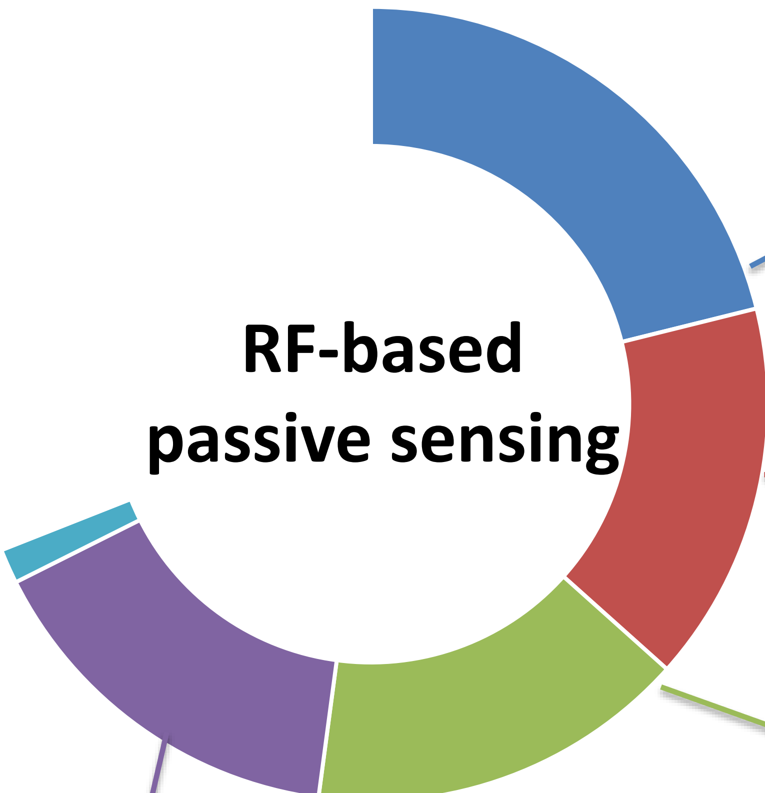
Gesture recognition

[WiSee’13], [E-eyes‘14], [WiDeo’15], [WiDraw‘15], [D-Watch’16]...

Current Solutions



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Gesture recognition

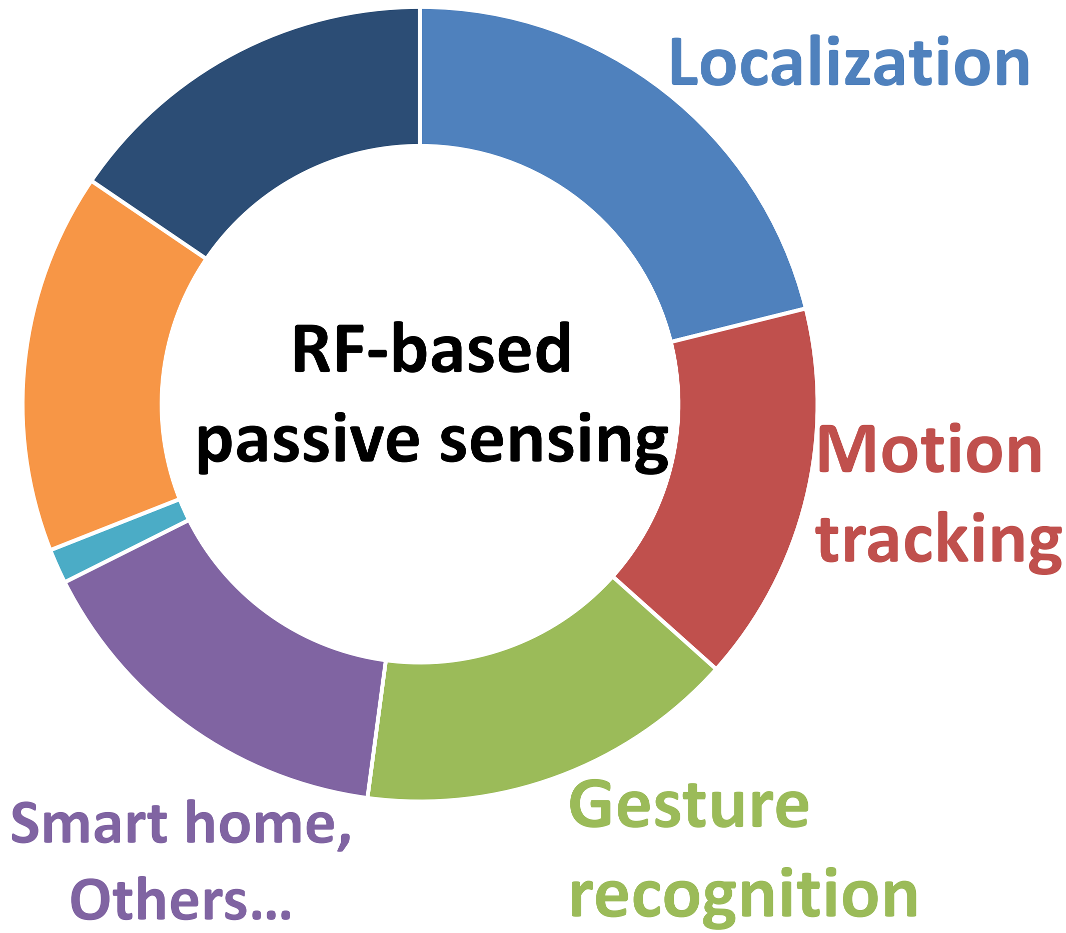
[WiSee’13], [E-eyes‘14], [WiDeo’15], [WiDraw‘15], [D-Watch’16]...

Smart home,
Others…

Missing: target imaging and material identification

Target Imaging

Material Identification



Applications of Target Imaging and Material Identification

Robot Control

Robot adjusts its grip strength when picking egg and stone by using material identification

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Security checking

Detecting concealed weapons by knowing target shape and material type

TagScan

A system identifies a target's material and images its shape simultaneously

- ***Low cost*:**
  – cheap commodity RFID device.
- ***High accuracy*:**
  – differentiating even Coke and Pepsi.
  – Imaging the body shape accurately.
- ***Easy deployment*:**
  – Utilizing the phase and RSS readings.

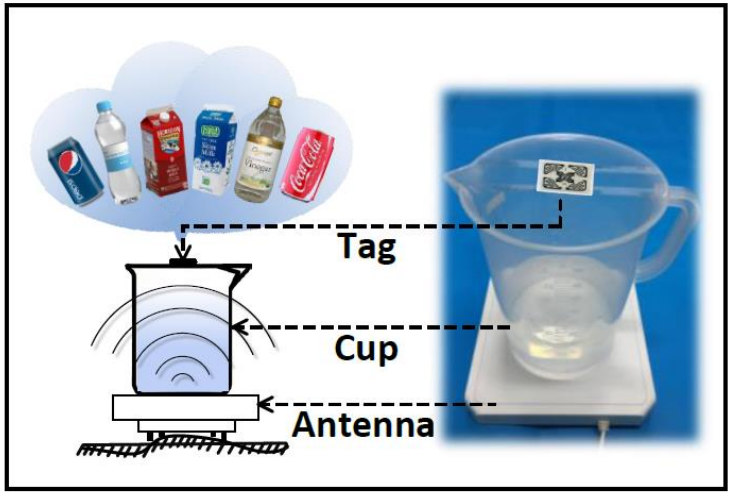
How can we identify a target's material?

How can we image a target's shape?

Preliminary studies

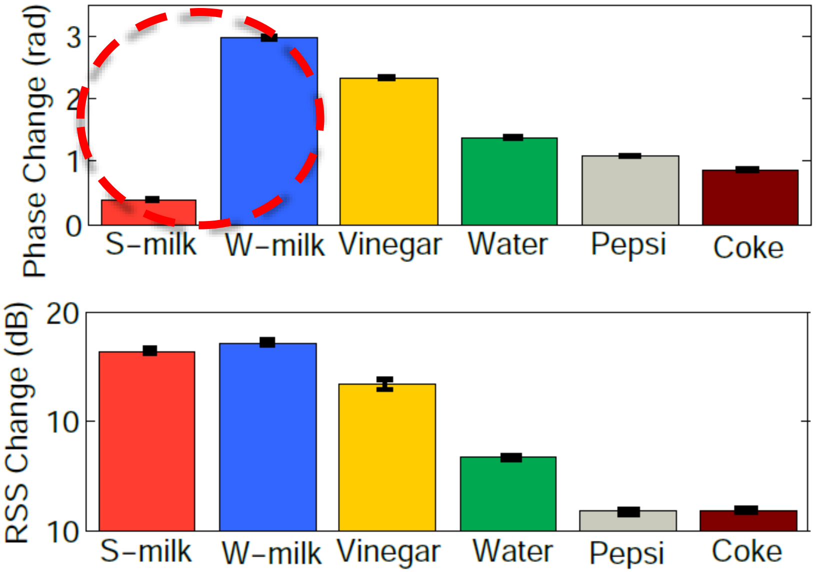
Setup:

Place RFID tag on top of the cup and pour the **same amount** of liquid.

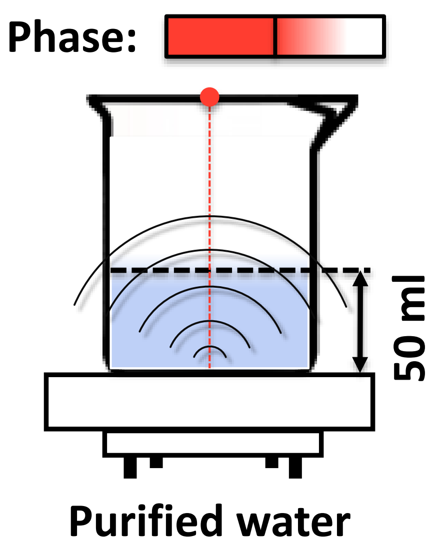


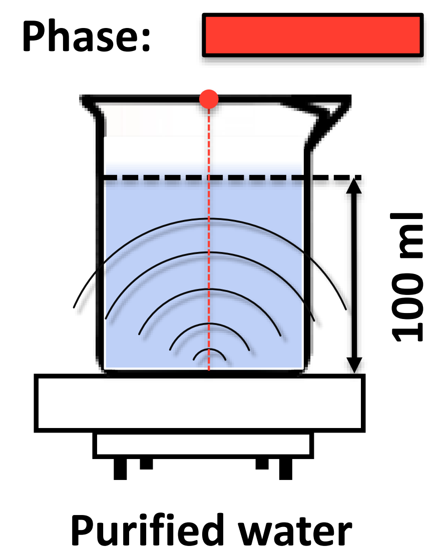
Key Observations:

- Different liquids have different Phase/RSS changes.
- Even Coke and Pepsi have an around 0.2 radians phase change difference.



Challenge : Without knowing the target size, identifying material type is challenging

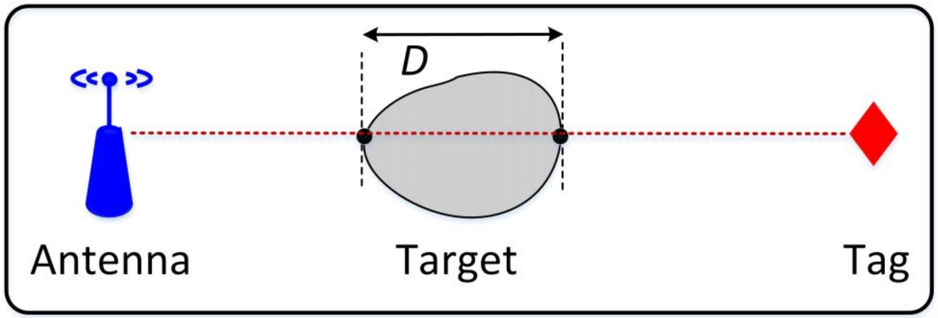




Material Feature Extraction

Background and limitation of past approaches

Considering a target that blocks the direct path:



RF propagation property

> Phase constant β: Phase changes β over a wavelength.

> Attenuation constant α: amplitude changes $e^{-\alpha}$ over a unit distance.

With Phase change $\Delta\emptyset$ and RSS change ΔR, we have:

$$-\Delta\emptyset = 2(\beta_{air} - \beta_{tar})D$$
$$\ln 10^{\Delta R/20} = 2(\alpha_{air} - \alpha_{tar})D$$

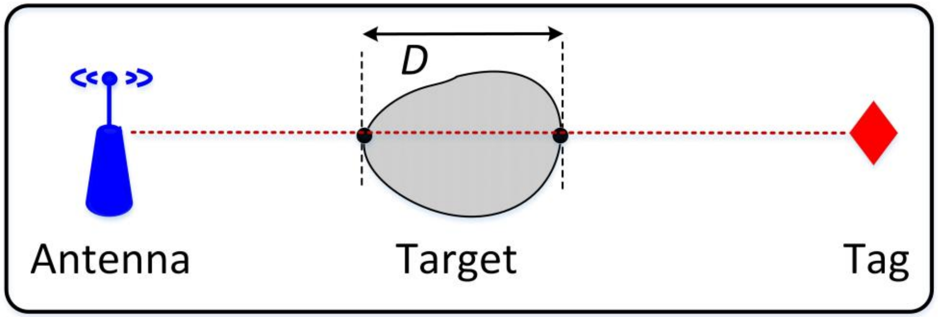
Measurements — Constant — Unique for each material type

Past approaches use α_{tar} and β_{tar} for material identification

Material Feature Extraction

Background and limitation of past approaches

Considering a target that blocks the direct path:



RF propagation property

> Phase constant β: Phase changes β over a wavelength.

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With Phase change $\Delta\emptyset$ and RSS change ΔR, we have:

2 Equations

$$\begin{cases} -\Delta\emptyset = 2(\beta_{air} - \boxed{\beta_{tar}})D \\ \ln 10^{\Delta R/20} = 2(\alpha_{air} - \boxed{\alpha_{tar}})D \end{cases}$$

3 Unknowns

2 equations can not solve 3 unknowns!

Material Feature Extraction

Our solution:

By removing the unknown D, we define a feature:

$$\Omega = \frac{\ln 10^{\Delta R/20}}{\Delta \varnothing} = \boxed{\frac{\alpha_{air} - \alpha_{tar}}{\beta_{tar} - \beta_{air}}}$$

Advantage:

- Ω is unique for each material and independent of D.

Material Feature Extraction

Our solution:

By removing the unknown D, we define a feature:

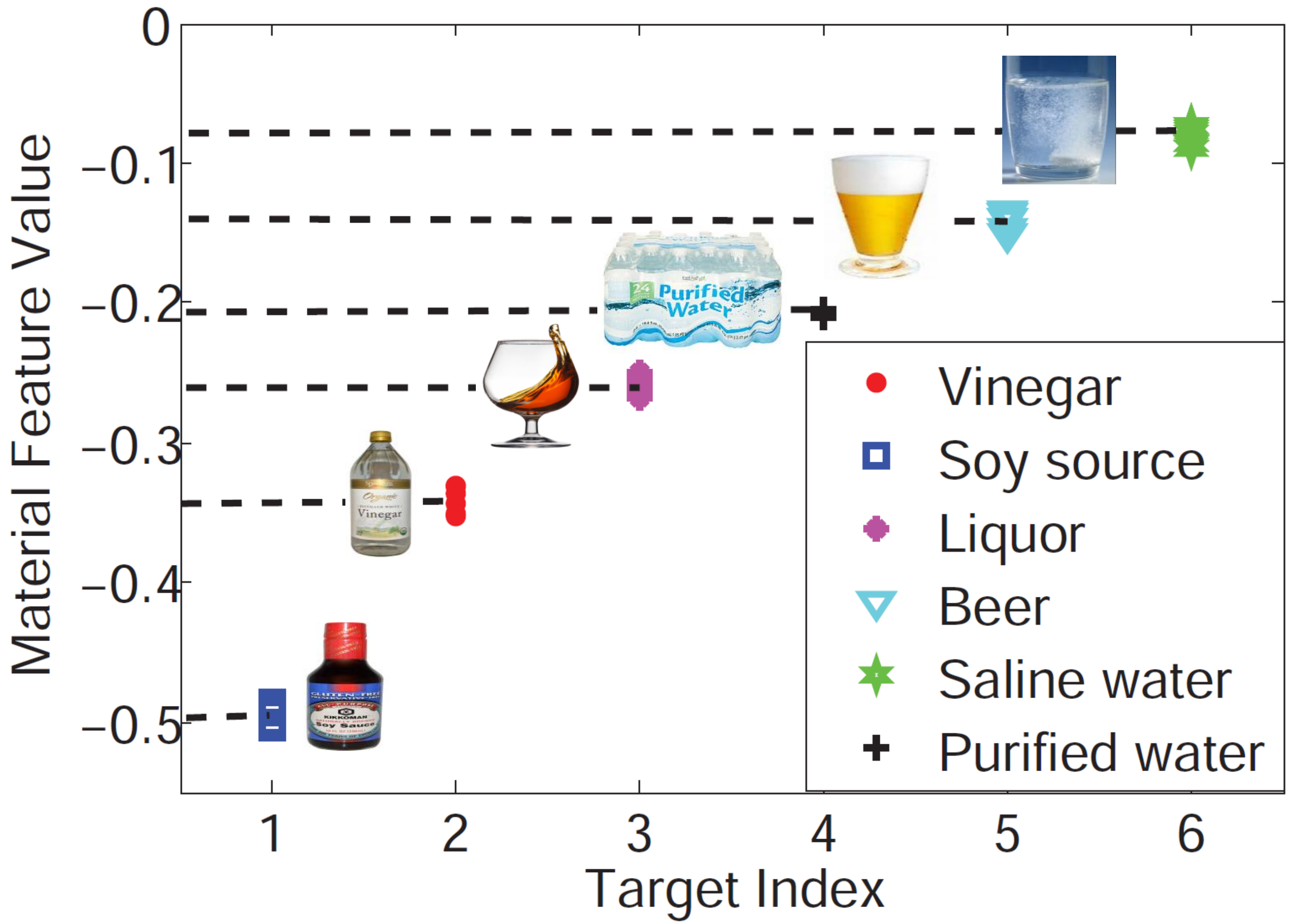
$$\Omega = \frac{\ln 10^{\Delta R/20}}{\Delta\phi} = \boxed{\frac{\alpha_{air} - \alpha_{tar}}{\beta_{tar} - \beta_{air}}}$$

Advantage:

- Ω is unique for each material and independent of D.
- Ω can be calculated from RSS and phase readings.

Without knowing the target size, we employ the new feature Ω for material identification

Differentiating materials with feature Ω



The Ω values of 6 liquids are different from each other.

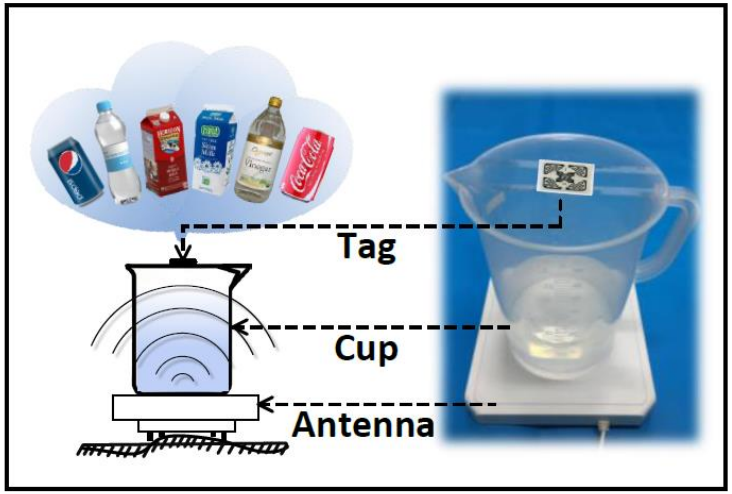
How can we identify a target's material?

How can we image a target's shape?

Preliminary studies

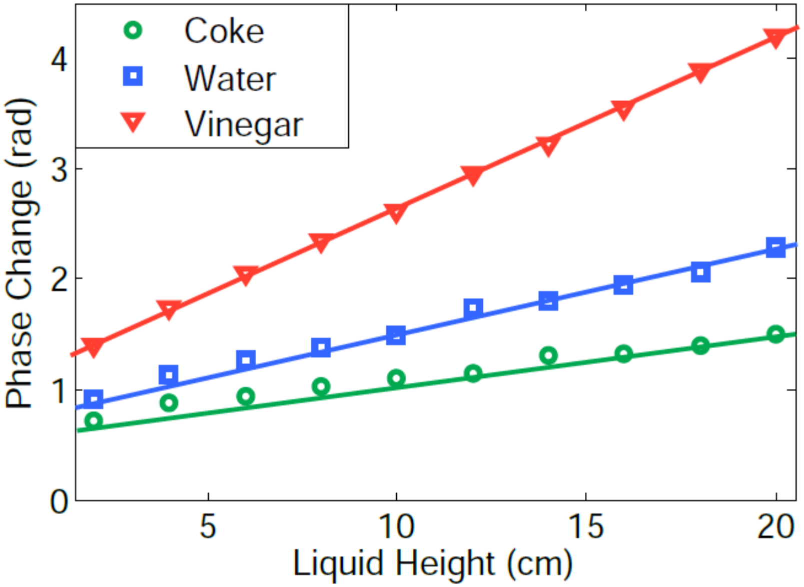
Setup:

Pour a liquid into the cup and increase the liquid height.

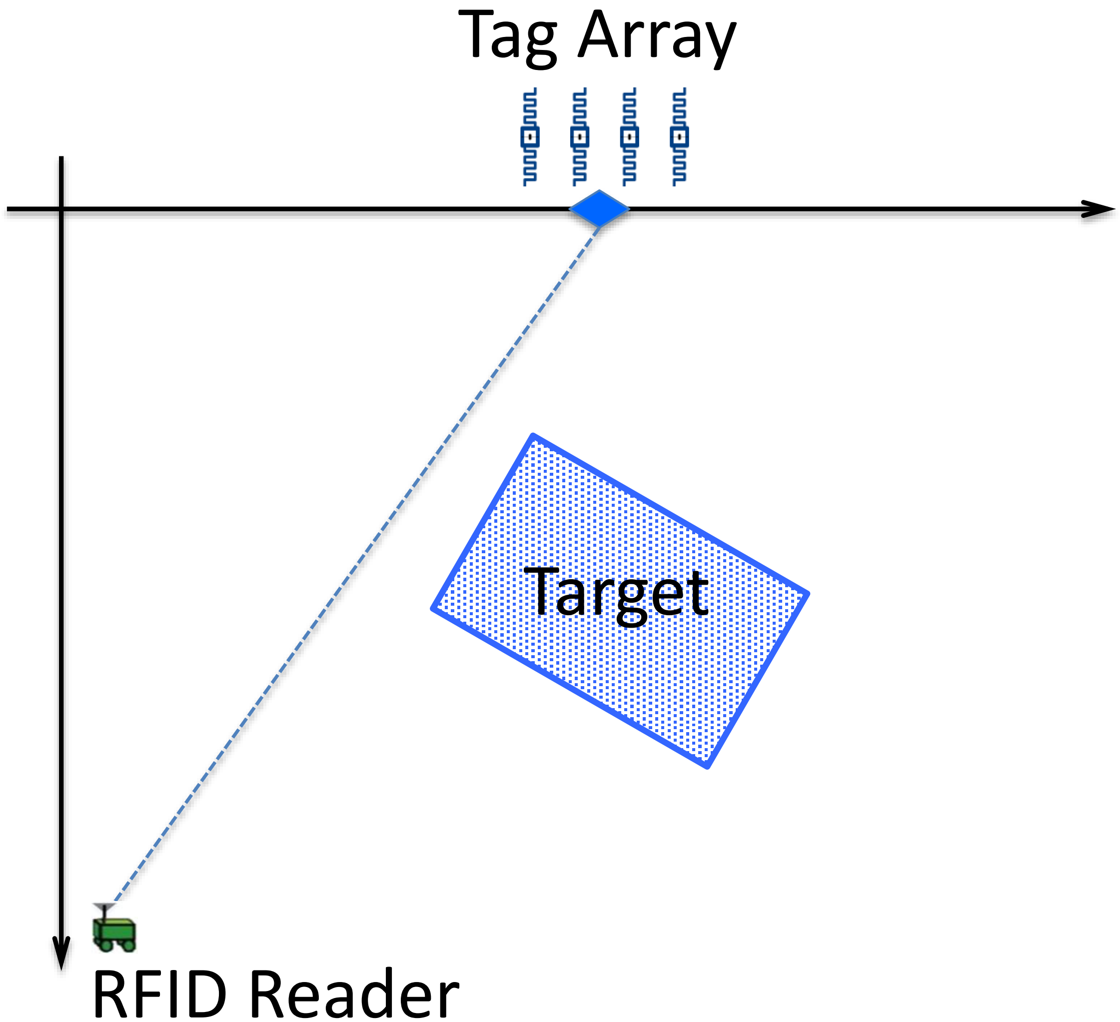


Key Observation:

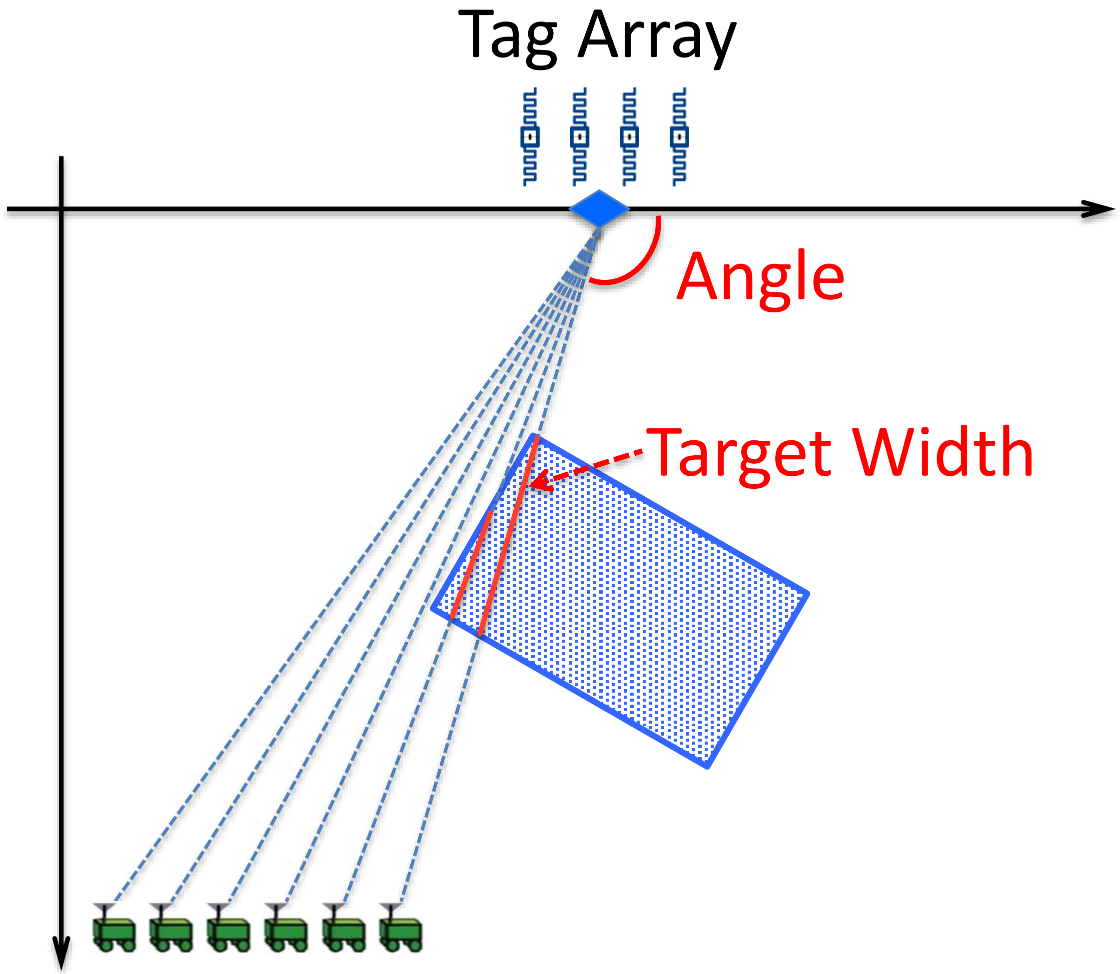
- Linear relationship between phase changes and liquid heights (i.e. target widths).



Basic Imaging Idea

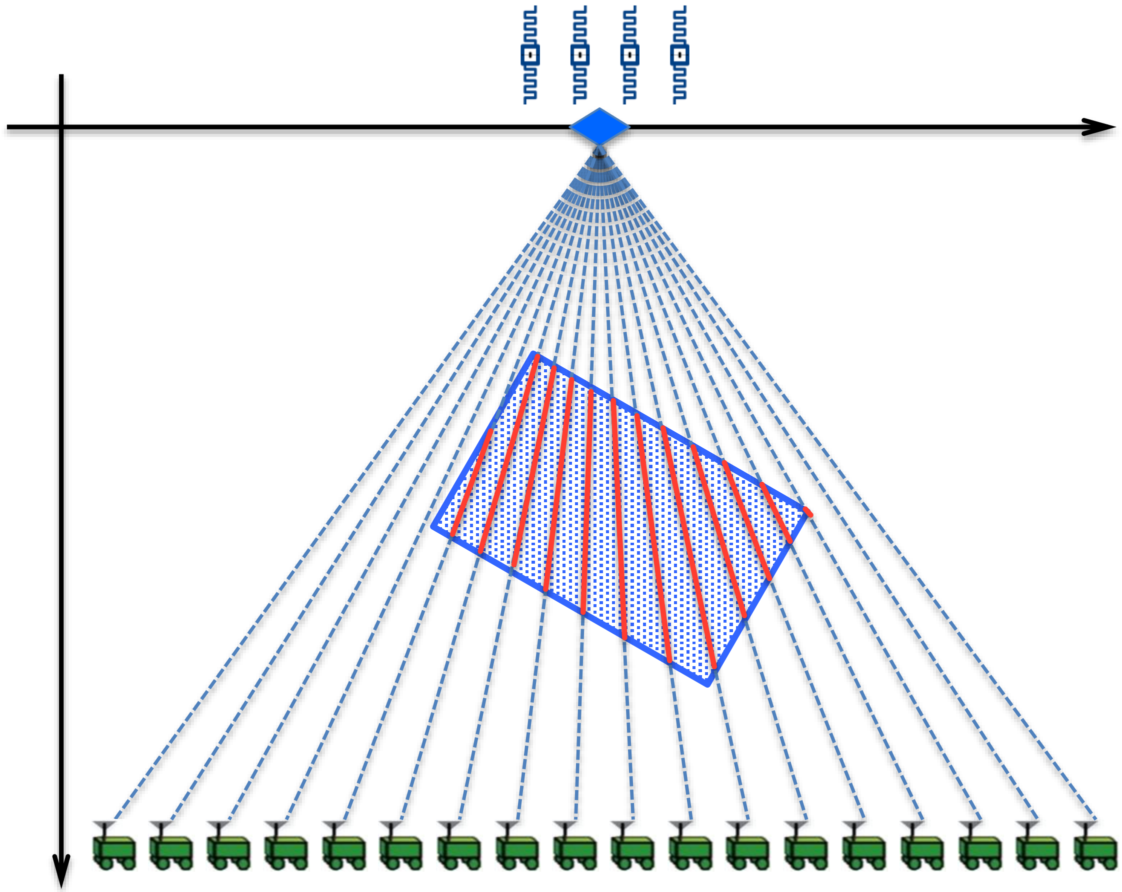


Basic Imaging Idea

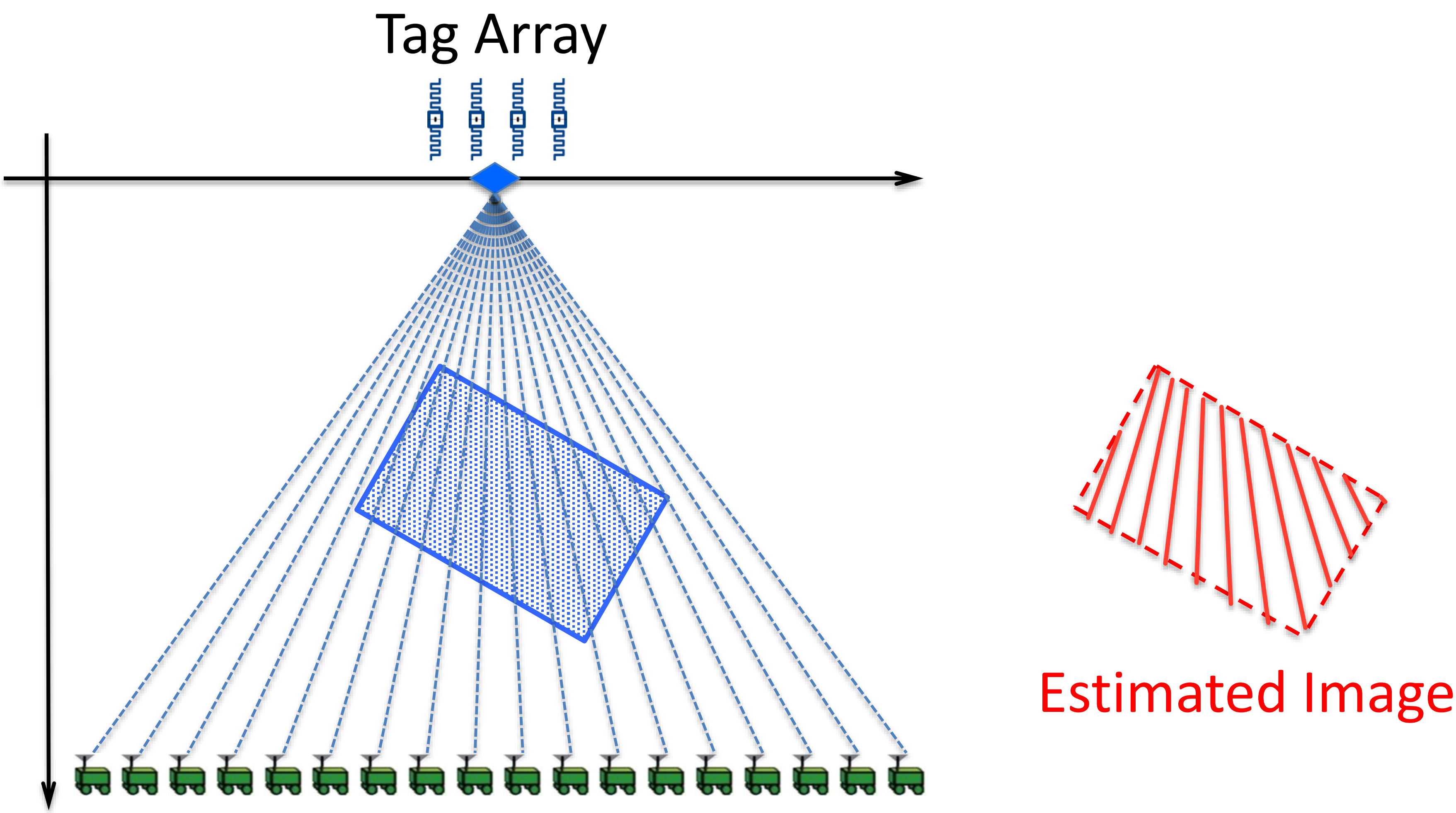


Basic Imaging Idea

Tag Array

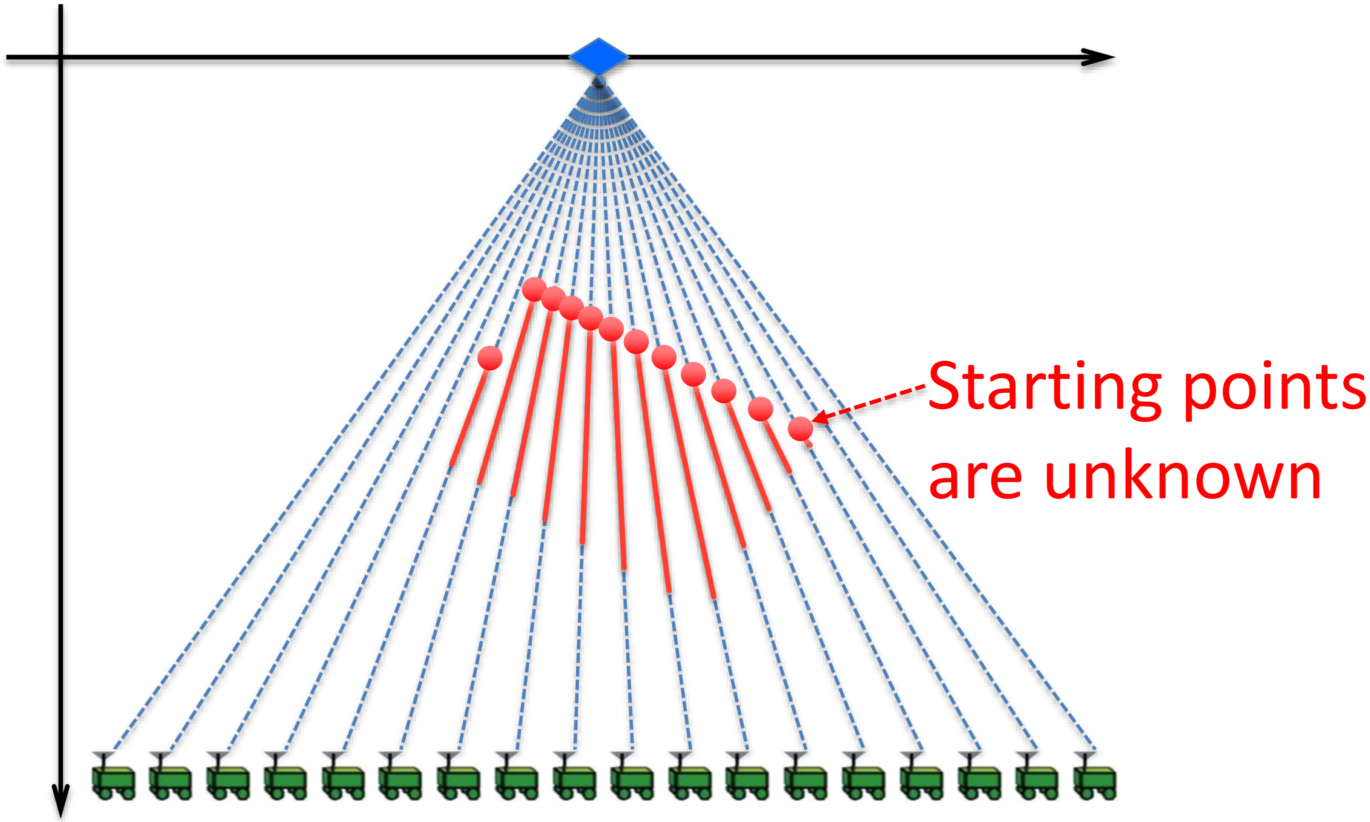


Basic Imaging Idea



Challenge :
Stitching target widths for imaging is non-trivial

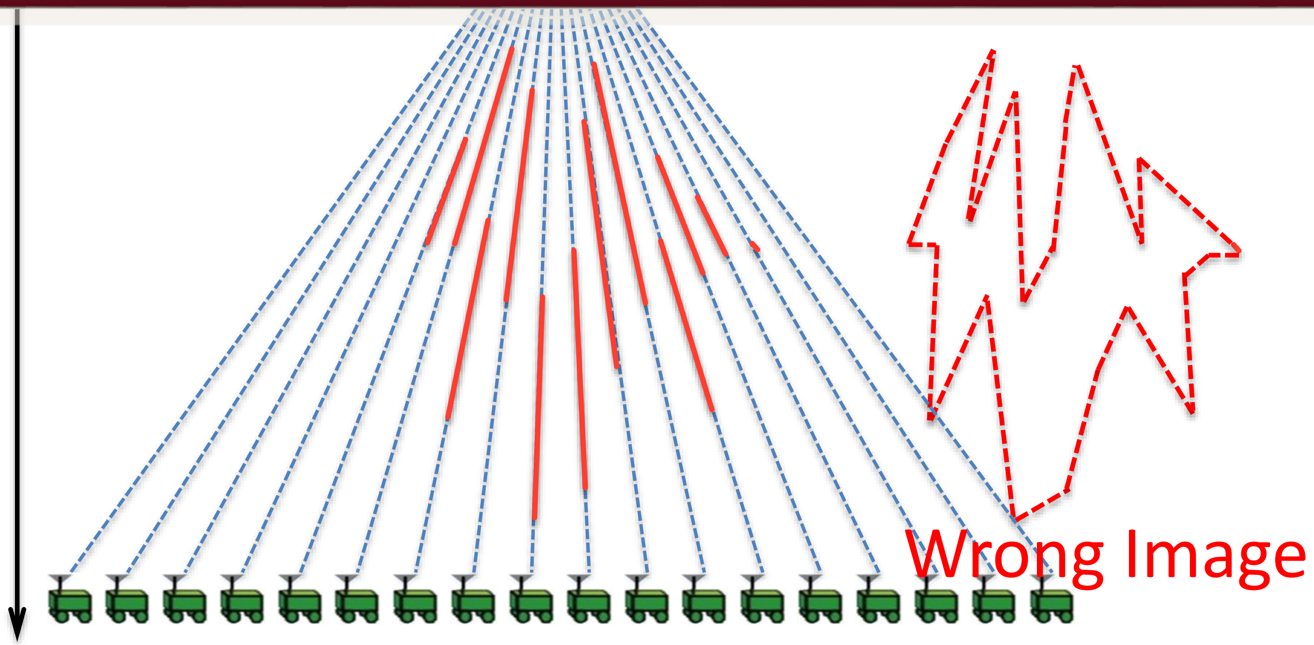
Starting points of target widths are unknown;



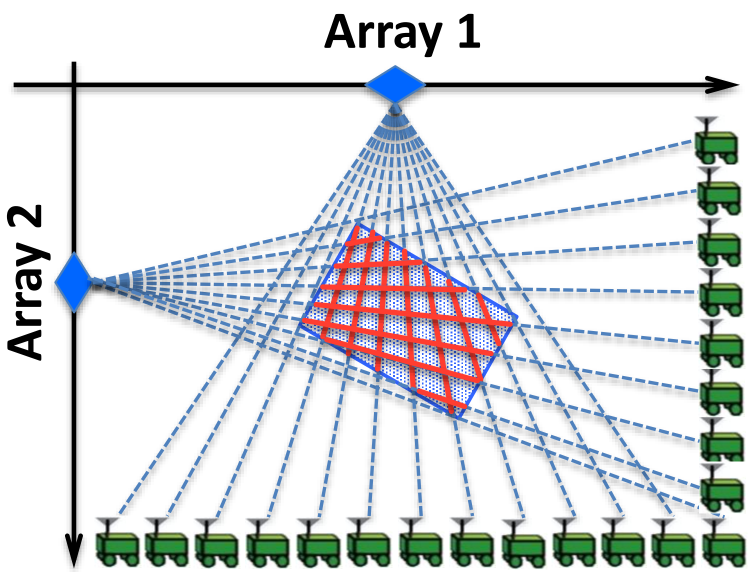
Starting points of target widths are unknown;

As a result, we may obtain wrong images:

How can we solve this problem?



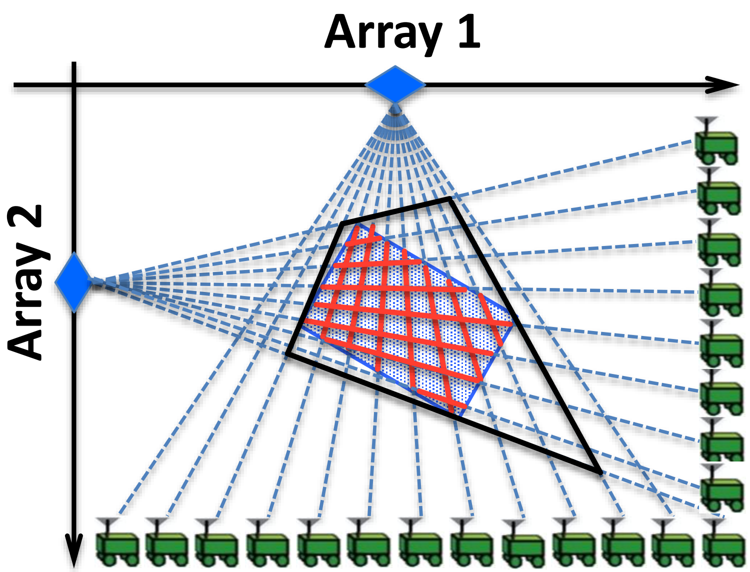
Solution: Imaging with Two Arrays



Key Observation:

- Images estimated from different arrays **align** well if the starting points are estimated correctly.

Solution: Imaging with Two Arrays



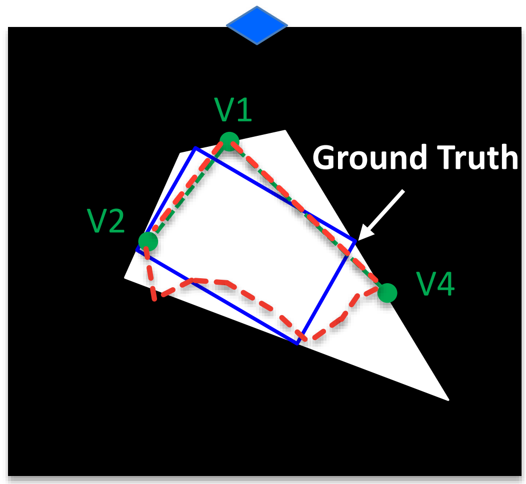


Image from Array 1

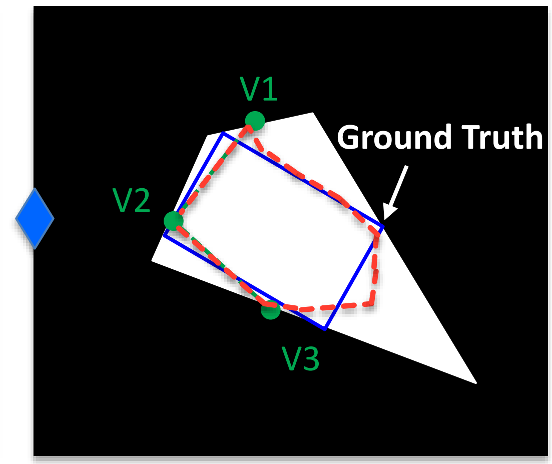
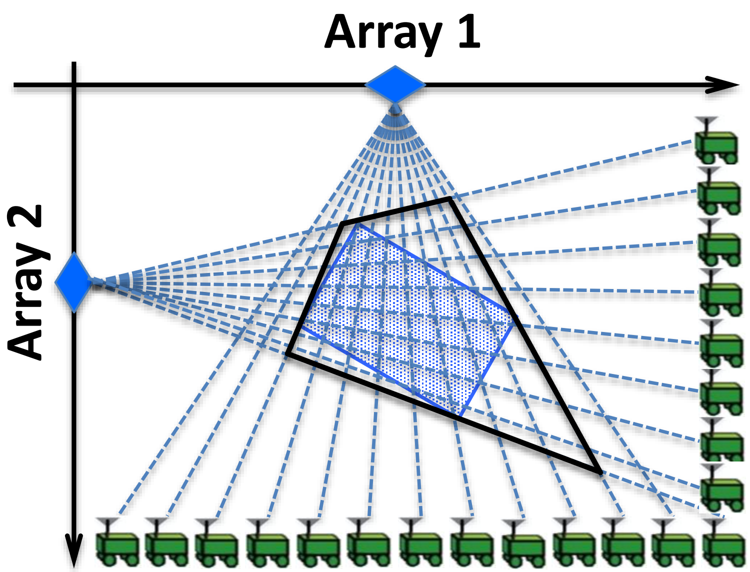


Image from Array 2

Solution: Imaging with Two Arrays



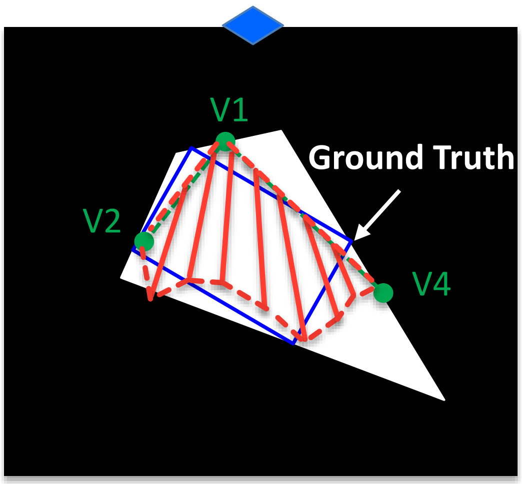


Image from Array 1

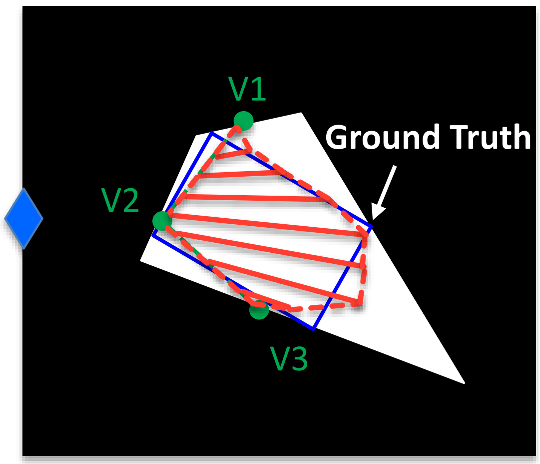
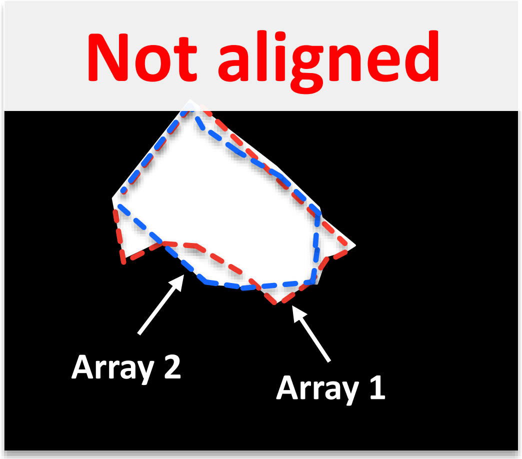
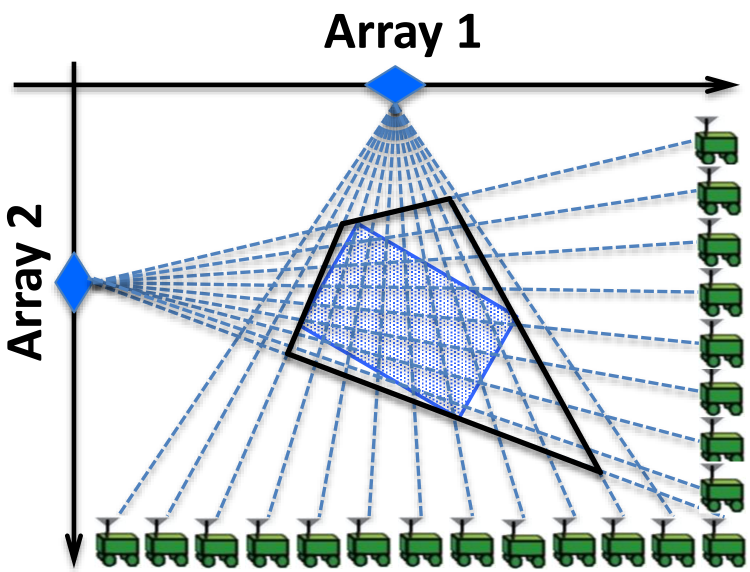


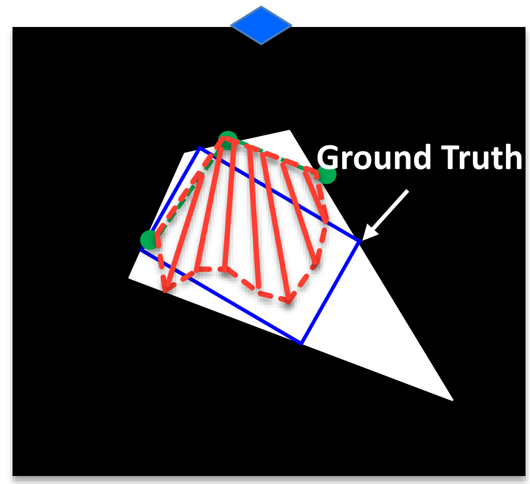
Image from Array 2



Initial image estimate

Solution: Imaging with Two Arrays





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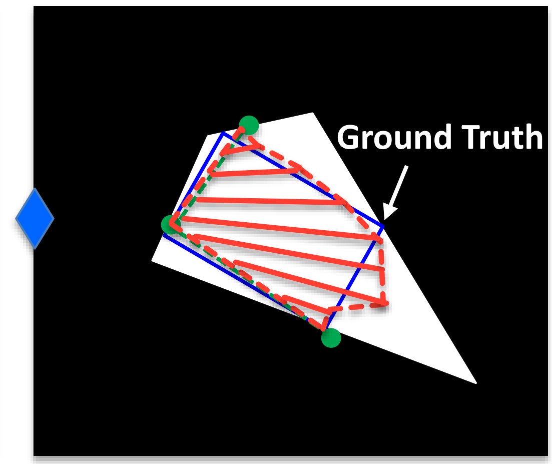
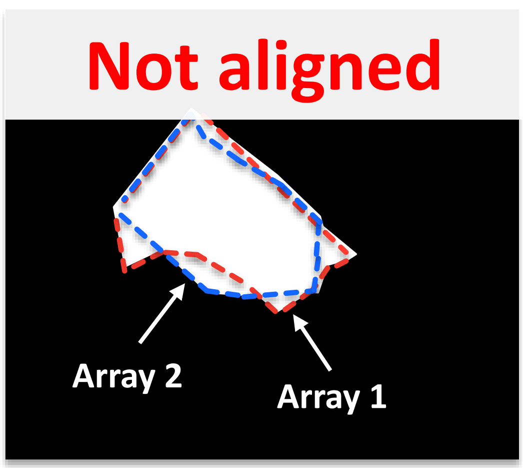
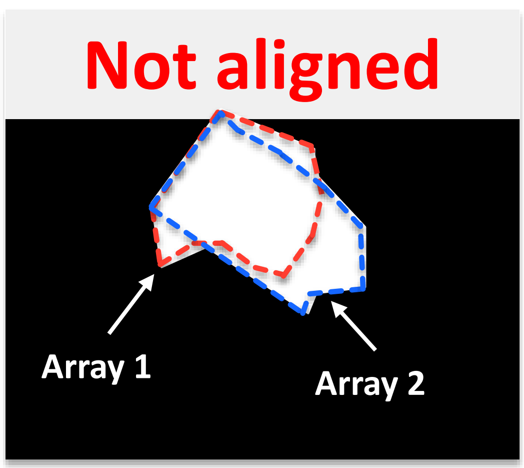


Image from Array 2

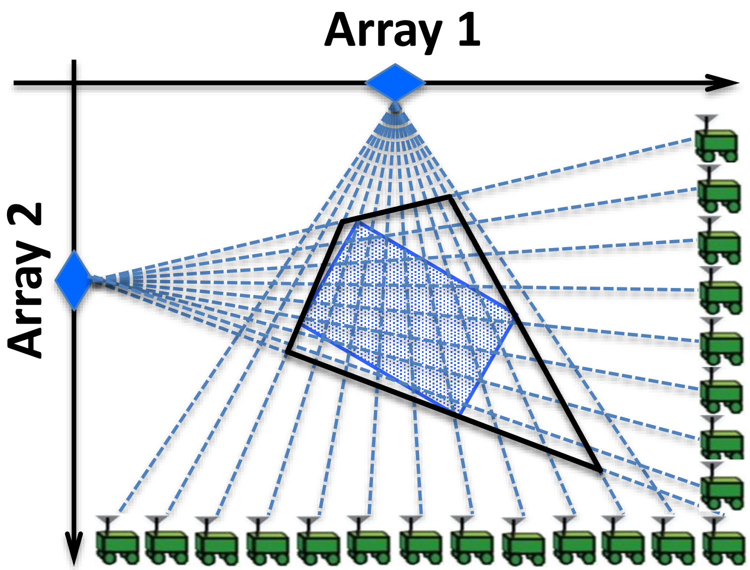


Initial image estimate



Another image estimate

Solution: Imaging with Two Arrays



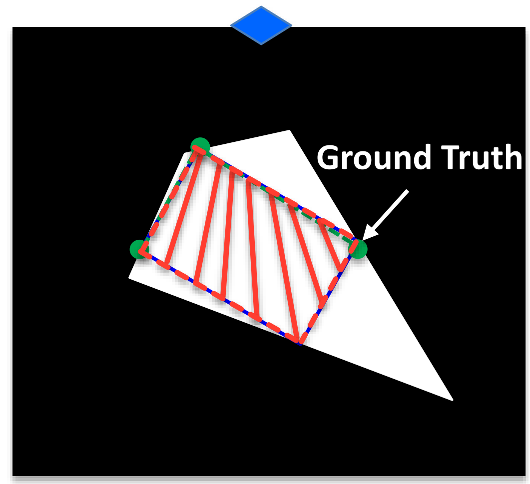


Image from Array 1

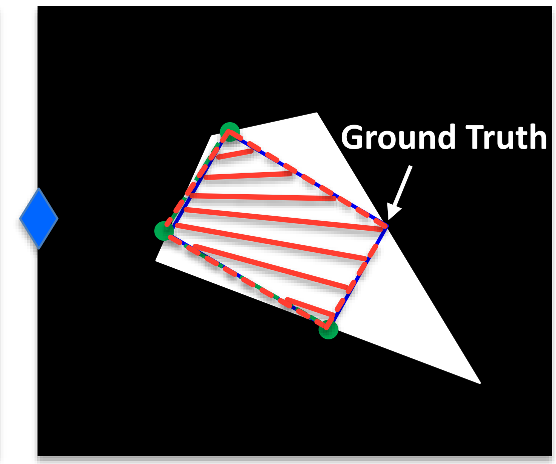
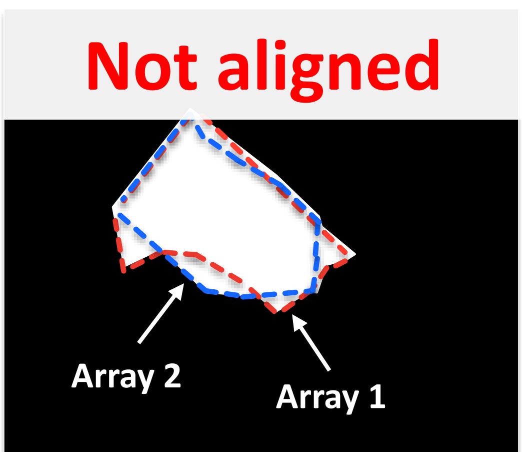
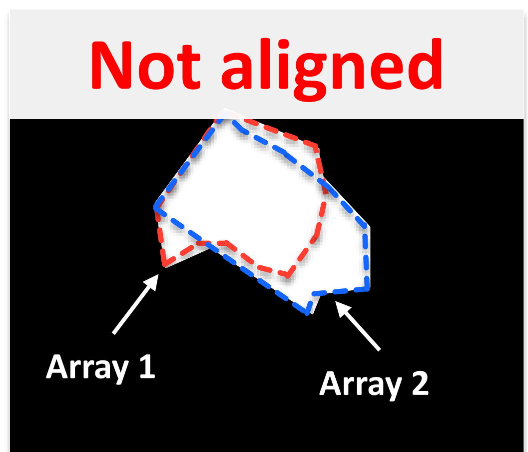


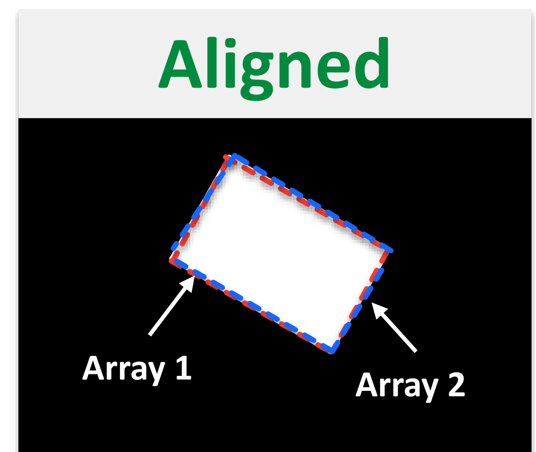
Image from Array 2



Initial image estimate



Another image estimate



Final image estimate

Multipath Problem:

Multipath signals break the linear relationship between phase change and target width

Solution: *Multipath Suppression*

Stage 1: Identifying the "clean" channels and tags

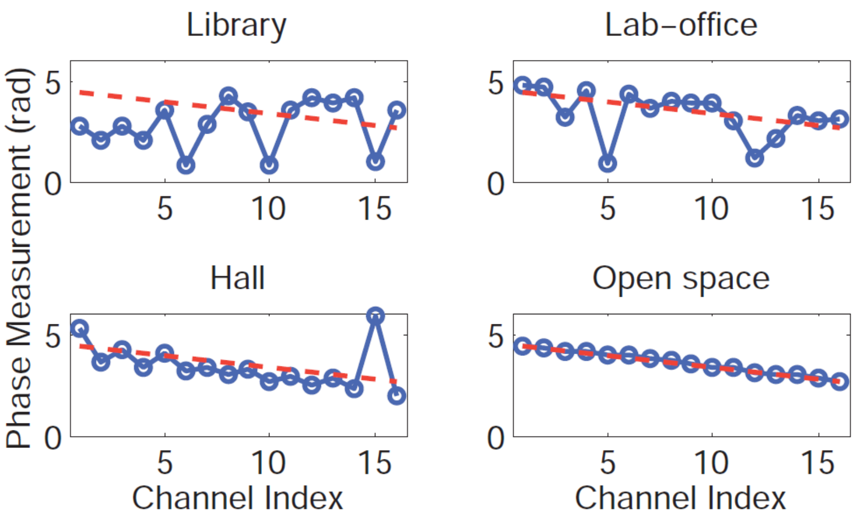


Fig. 1 Phase changes over different channels.

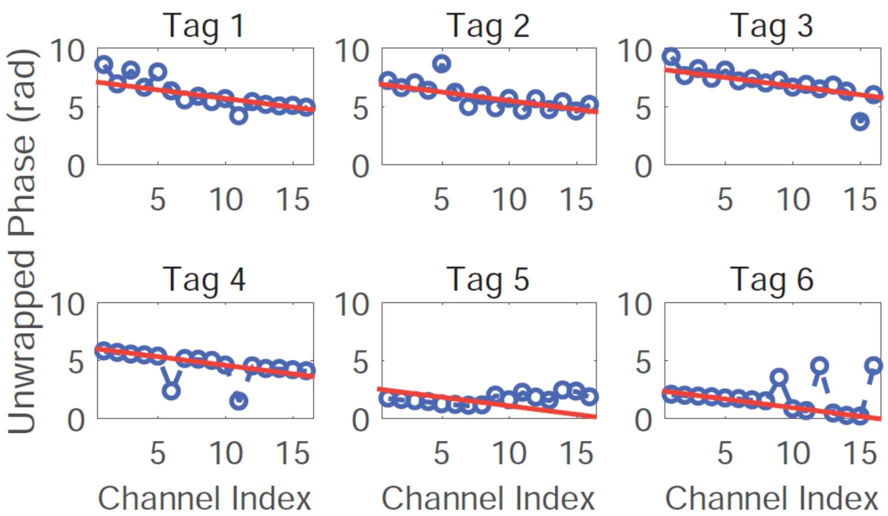
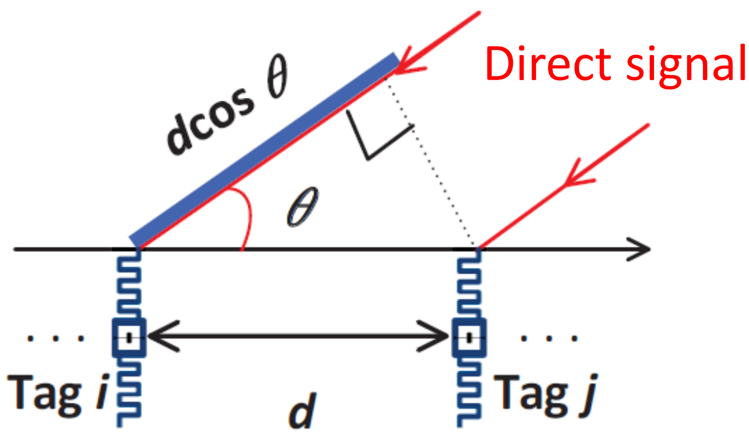


Fig. 2 Phase changes in hall environment.

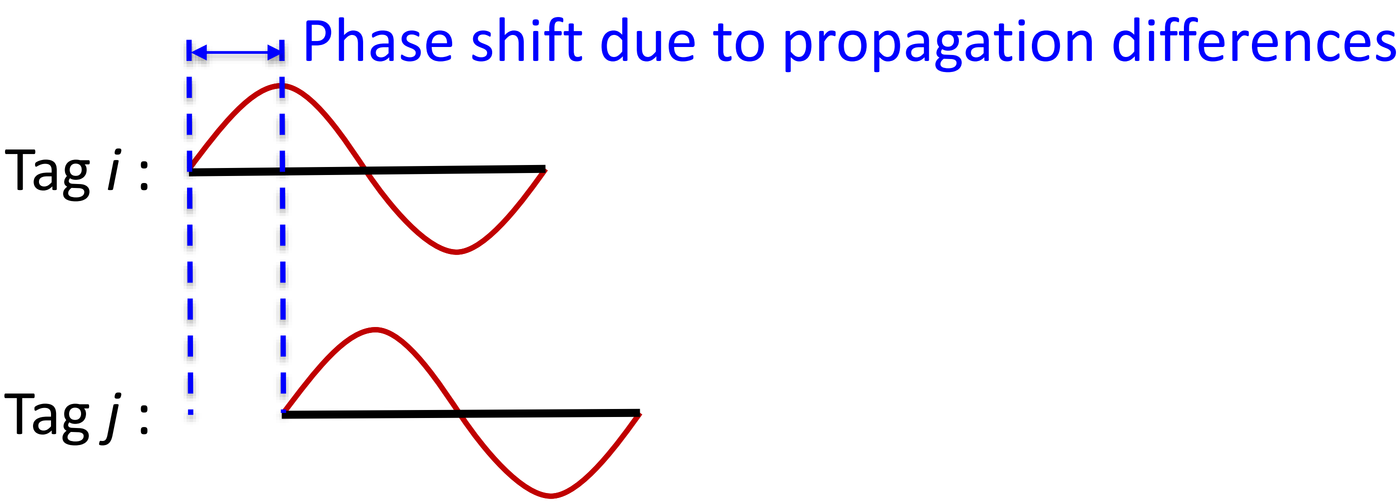
However, this works well only in the environment with little multipath

Solution: *Multipath Suppression*

Stage 2: Enhancing the direct-path signal

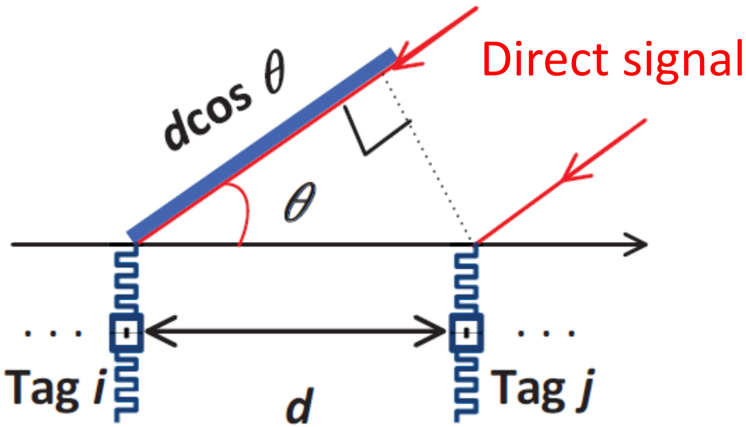


(a) Phase shift of $\frac{4\pi f}{C} d\cos(\theta)$ at two adjacent tags.

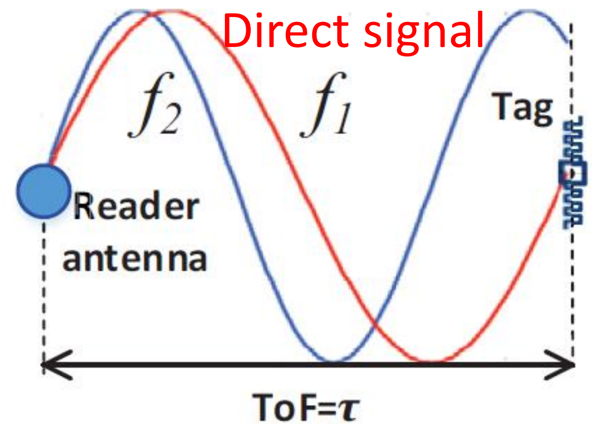


Solution: *Multipath Suppression*

Stage 2: Enhancing the direct-path signal

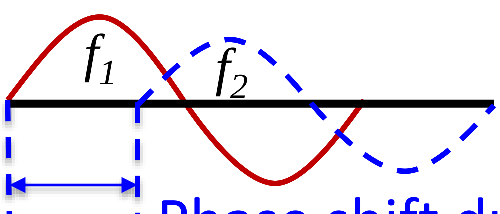


(a) Phase shift of $\frac{4\pi f}{C} d\cos(\theta)$ at two adjacent tags.



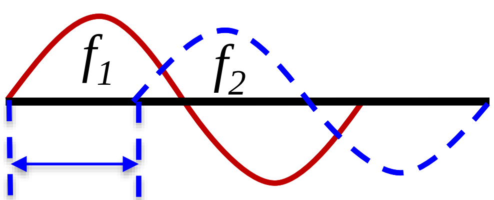
(b) Phase shift of $4\pi\tau\Delta f$ at two adjacent channels.

Tag *i* :



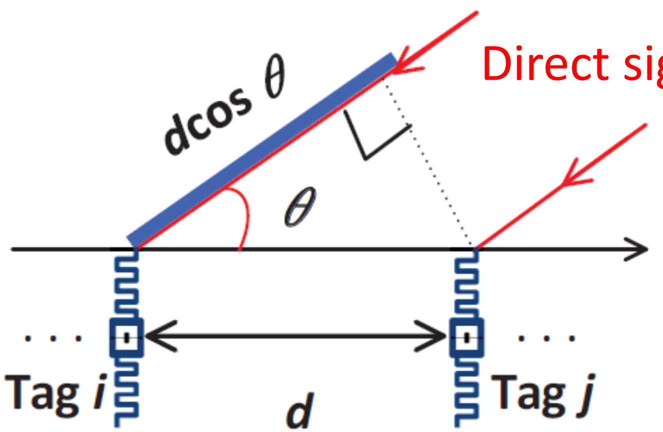
Phase shift due to frequency differences

Tag *j* :

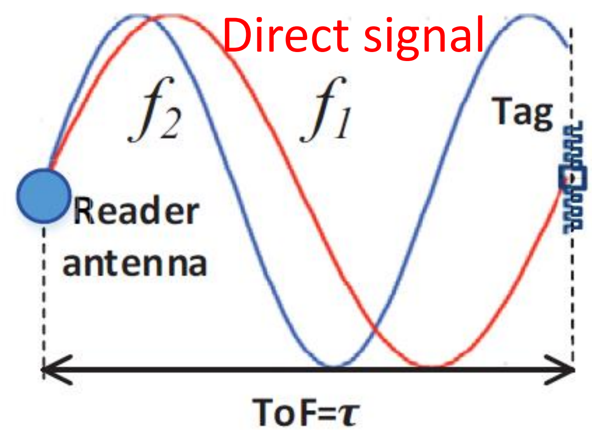


Solution: *Multipath Suppression*

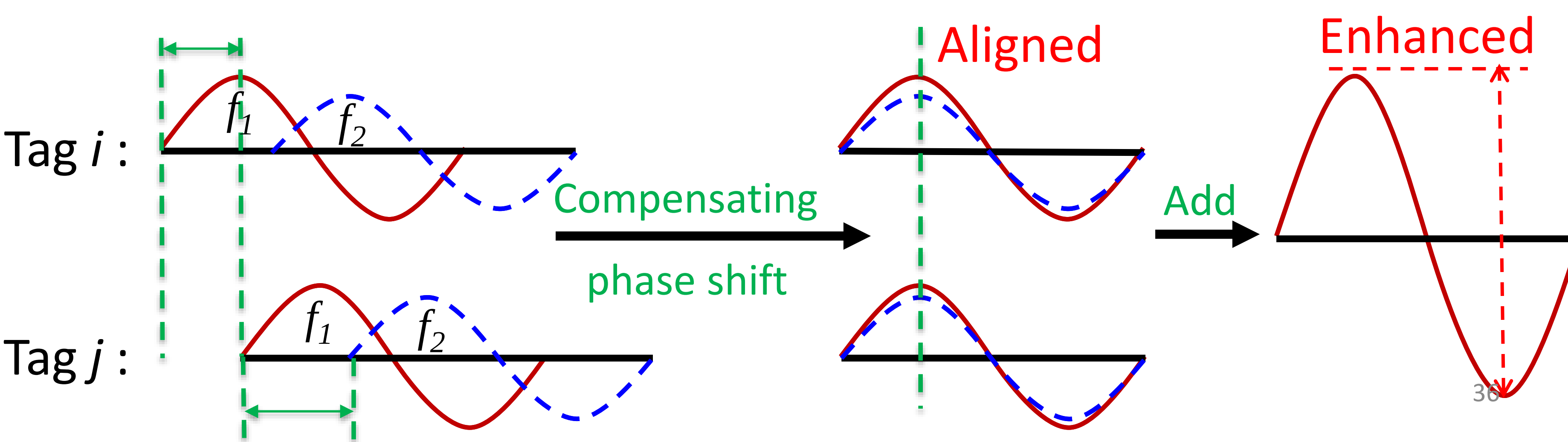
Stage 2: Enhancing the direct-path signal



(a) Phase shift of $\frac{4\pi f}{C} d\cos(\theta)$ at two adjacent tags.



(b) Phase shift of $4\pi\tau\Delta f$ at two adjacent channels.



Implementation & Evaluation

Implementation

- **Reader and Tag**: **one** Impinj Speedway R420 readers; **16** cheap Alien ALN-9634 tags.
- **Environments**: Hall, lab-office and library, w.r.t, ***low, medium*** and ***high*** multipath.

Reader


Antenna


Tag

Material Identification Performance

Material Identification for 10 Liquids

	A	B	C	D	E	F	I	L	M	N
A	1									
B		0.94						0.06		
C			0.99				0.01			
D				1						
E					0.95				0.05	
F						0.99			0.01	
I							1			
L								1		
M						0.05			0.95	
N										1

A : Vinegar B : CoKe C : Soy Source D : Liquor E : Beer
F : Purified water I : Saline Water L : Sweet Water
M: Whole milk N: Skimmed milk

Material identification accuracy is higher than 94%.

Similar Liquid Material identification

Coke

Pepsi

	Coke	Pepsi
Coke	0.93	0.07
Pepsi	0.06	0.94

Higher than 90% accuracy for identifying Coke and Pepsi.

Skimmed milk

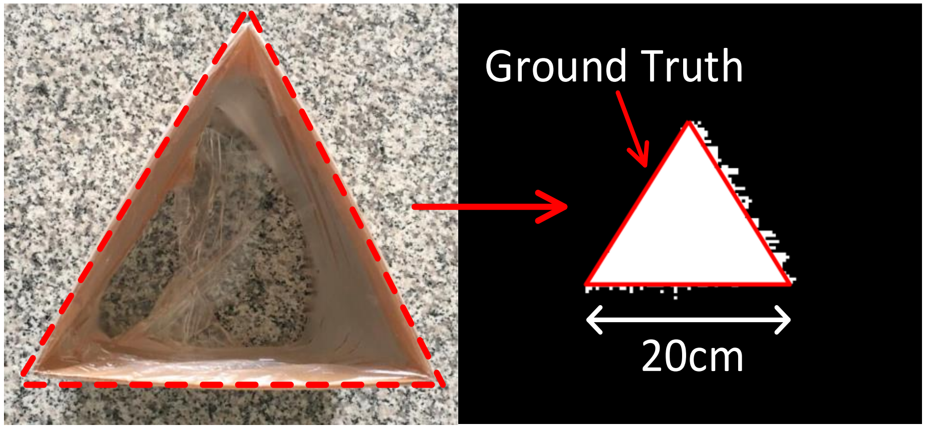
Whole milk

	Skimmed	Whole
Skimmed	1	
Whole		1

100% accuracy for identifying Skimmed and Whole milk.

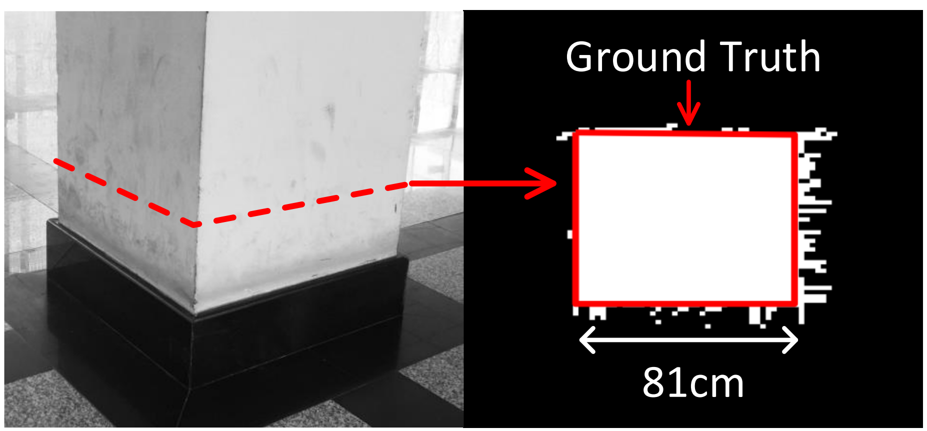
Target Imaging Performance

Imaging for Target with Different Shapes and Materials



Triangle shape (plastic & water)

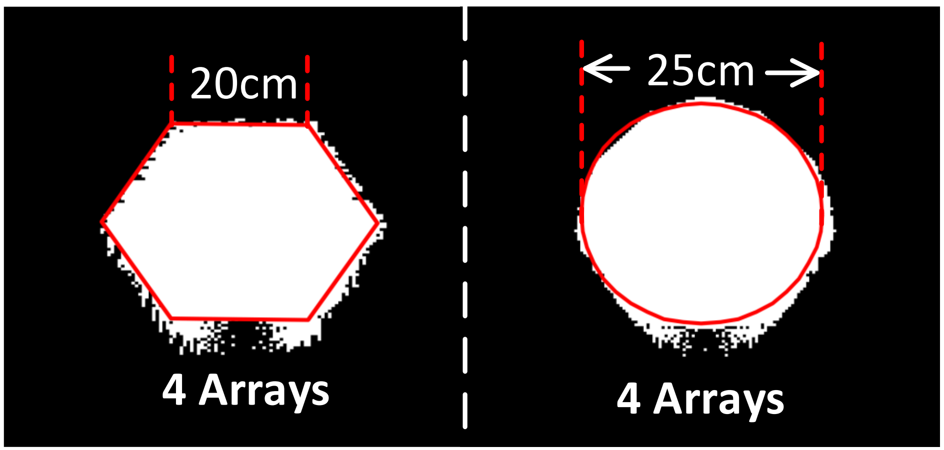
Hexagonal shape (plastic & water)



Rectangular shape cement pillar

Circular shape (plastic & water)

Imaging for Target with Different Shapes and Materials

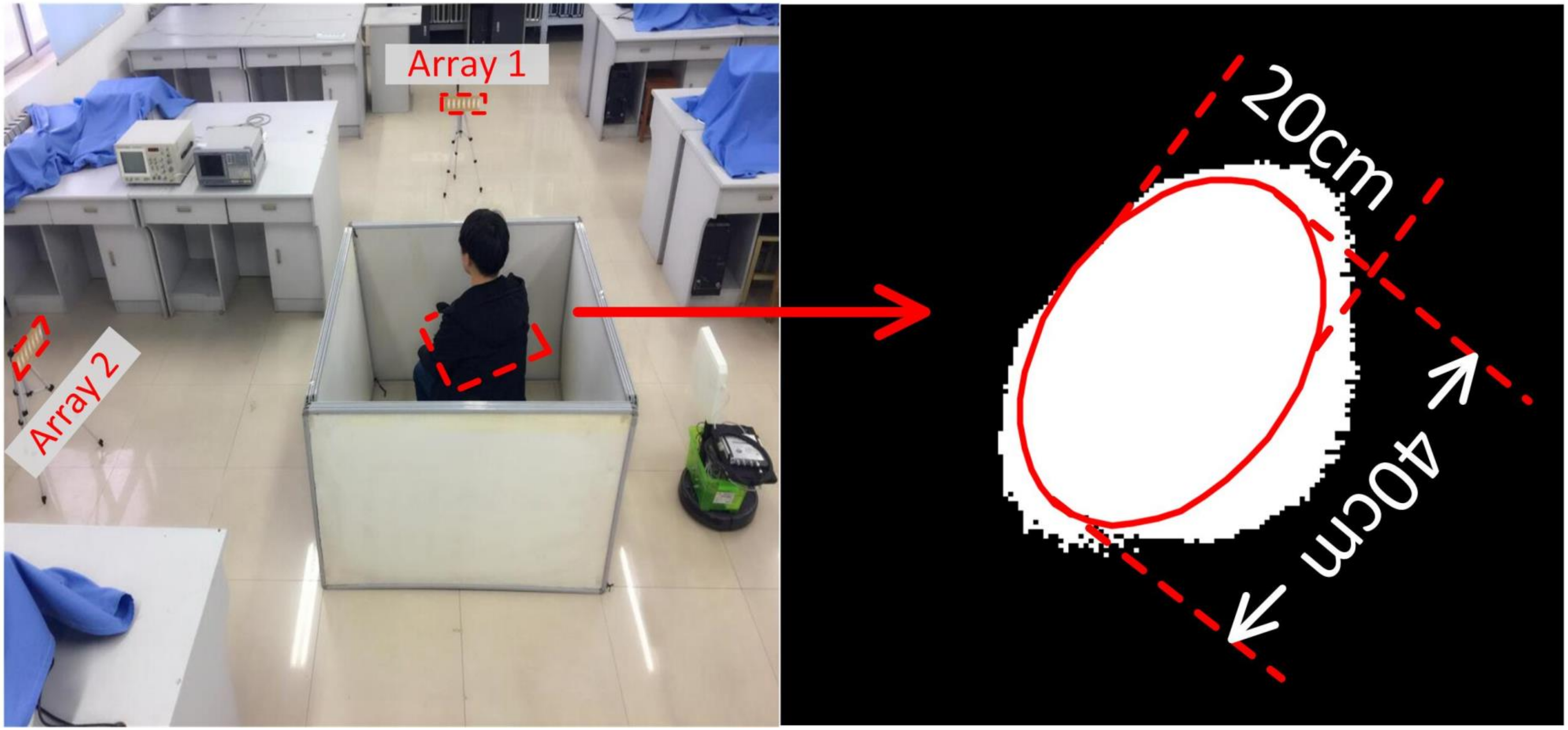


Two more arrays added!

Hexagonal shape (plastic & water)

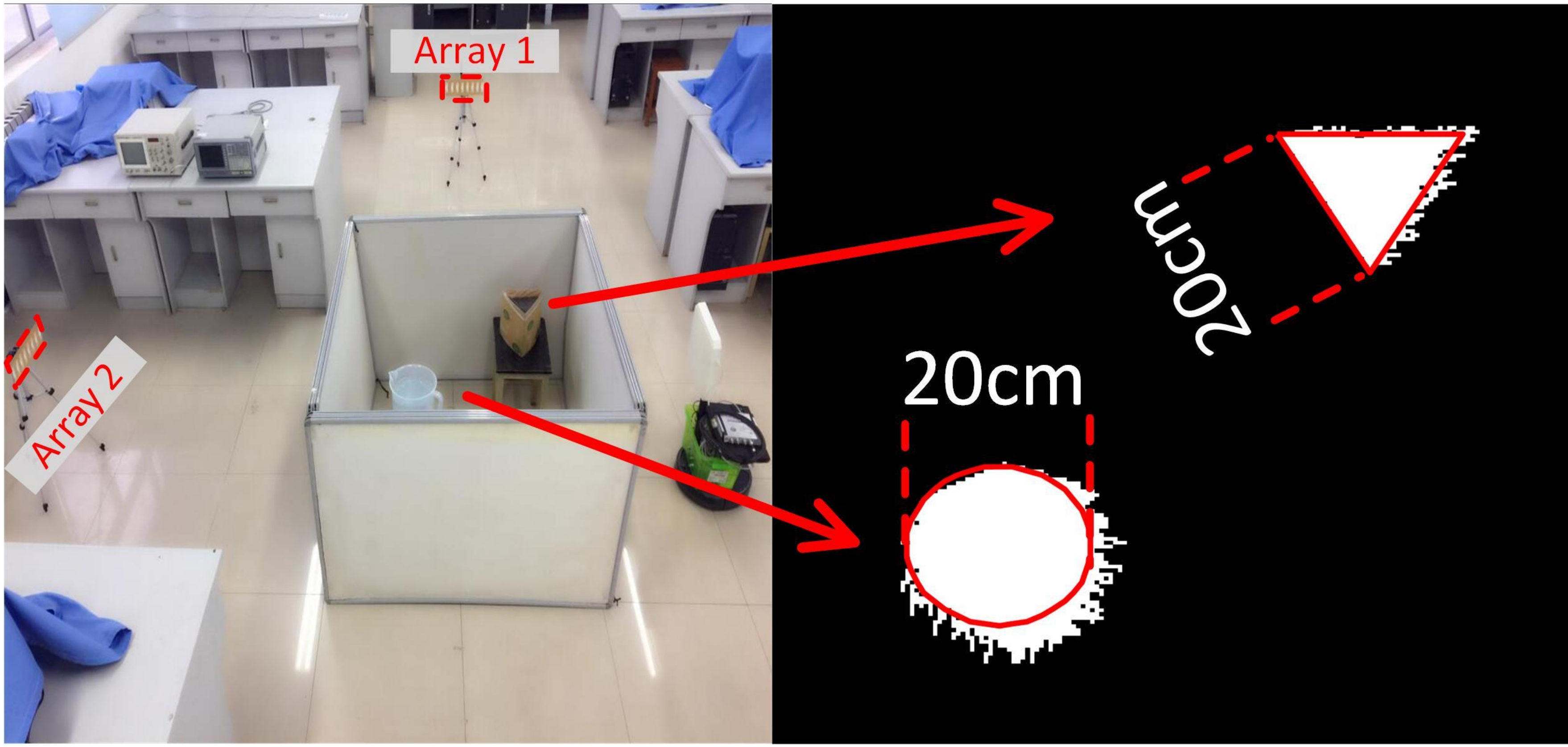
Circular shape (plastic & water)

See-through the wall imaging



Human target through wall imaging

See-through the wall imaging



Two-target through wall imaging

Conclusion

- TagScan performs material identification and target imaging *simultaneously*.
- A *new approach to identify materials,* independent of target size.
- A novel method for imaging targets, using RSS and phase.