Probabilistic 3D Sound Source Mapping using Moving Microphone Array

Sasaki et al., IROS 2016

Inkyu An

Content

1. Background
   - What is the Sound Source Localization?
2. Motivation
3. Approach
4. Result
5. Limitation

Content

1. **Background**
   - **What is the Sound Source Localization?**
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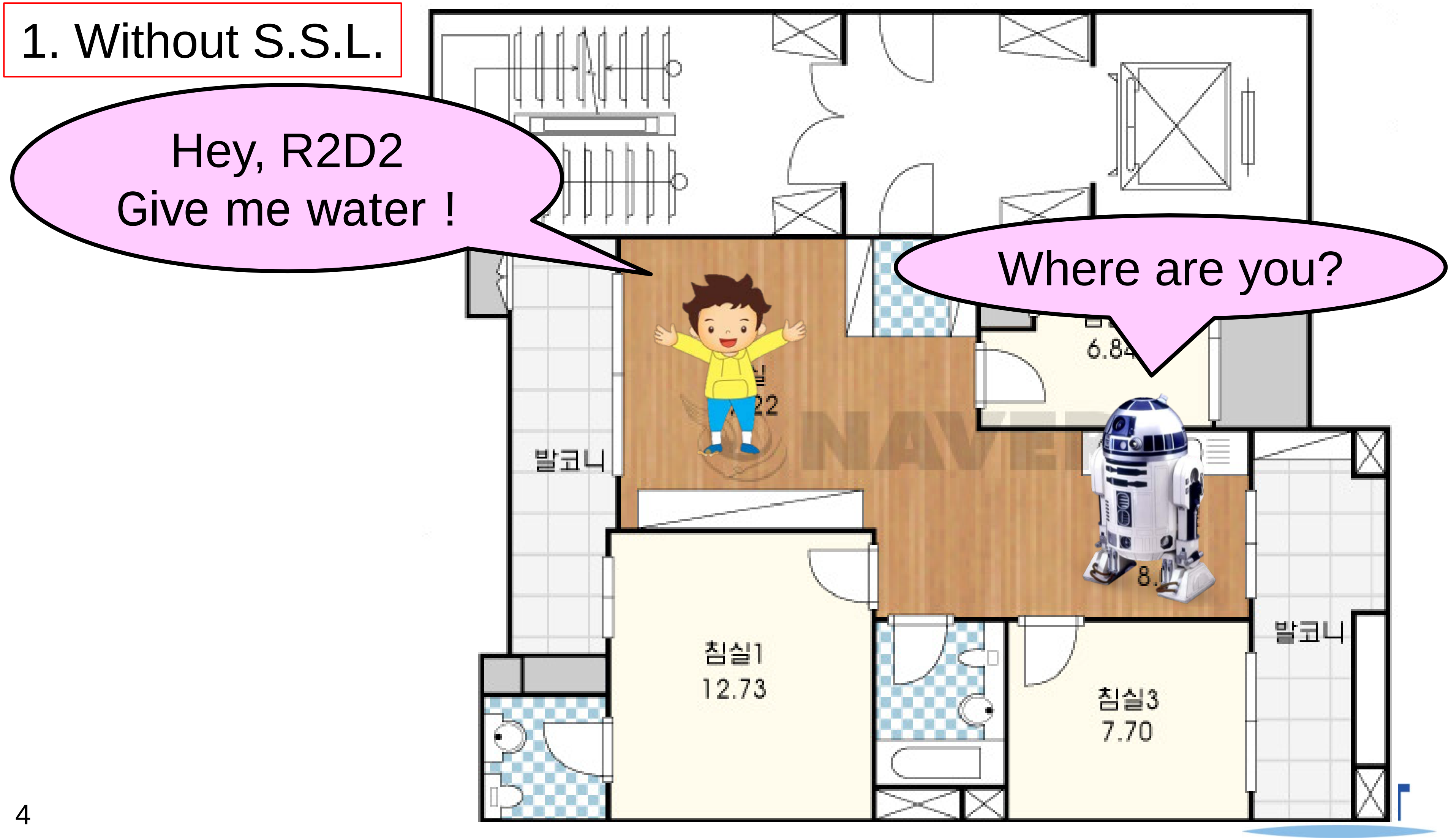
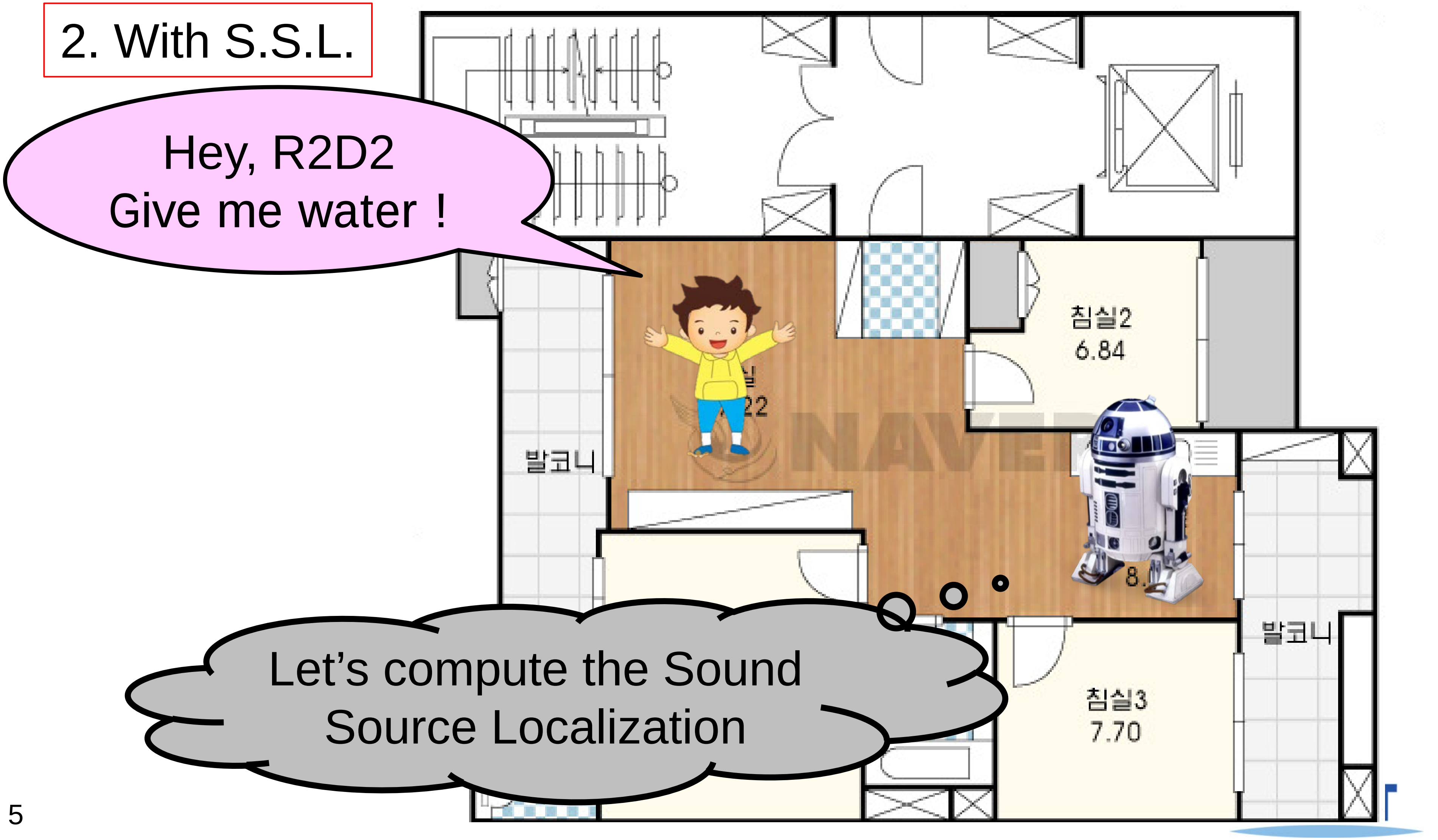
Background | What is the Sound Source Localization ?

1. Without S.S.L.



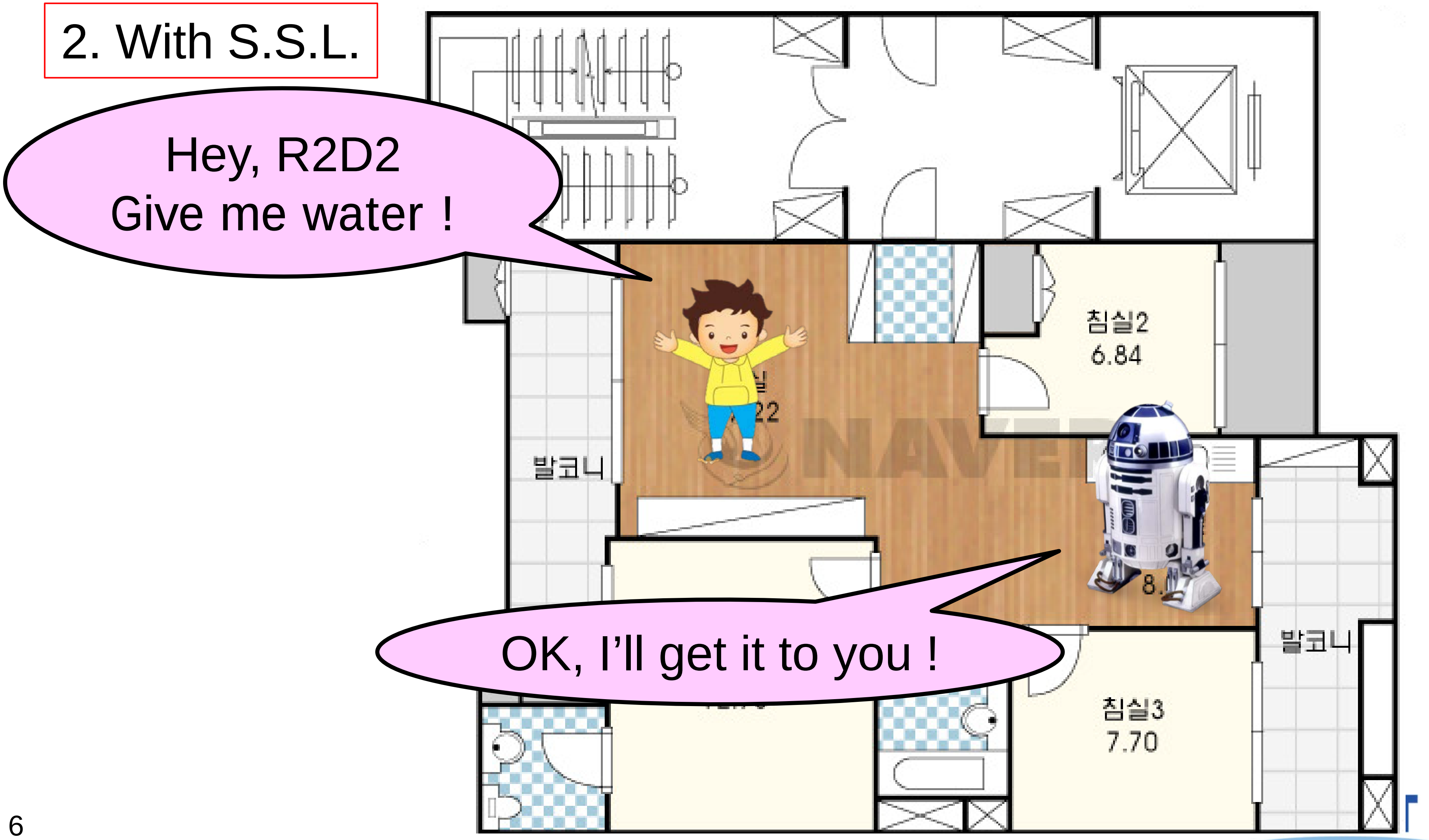
Background | What is the Sound Source Localization ?

2. With S.S.L.



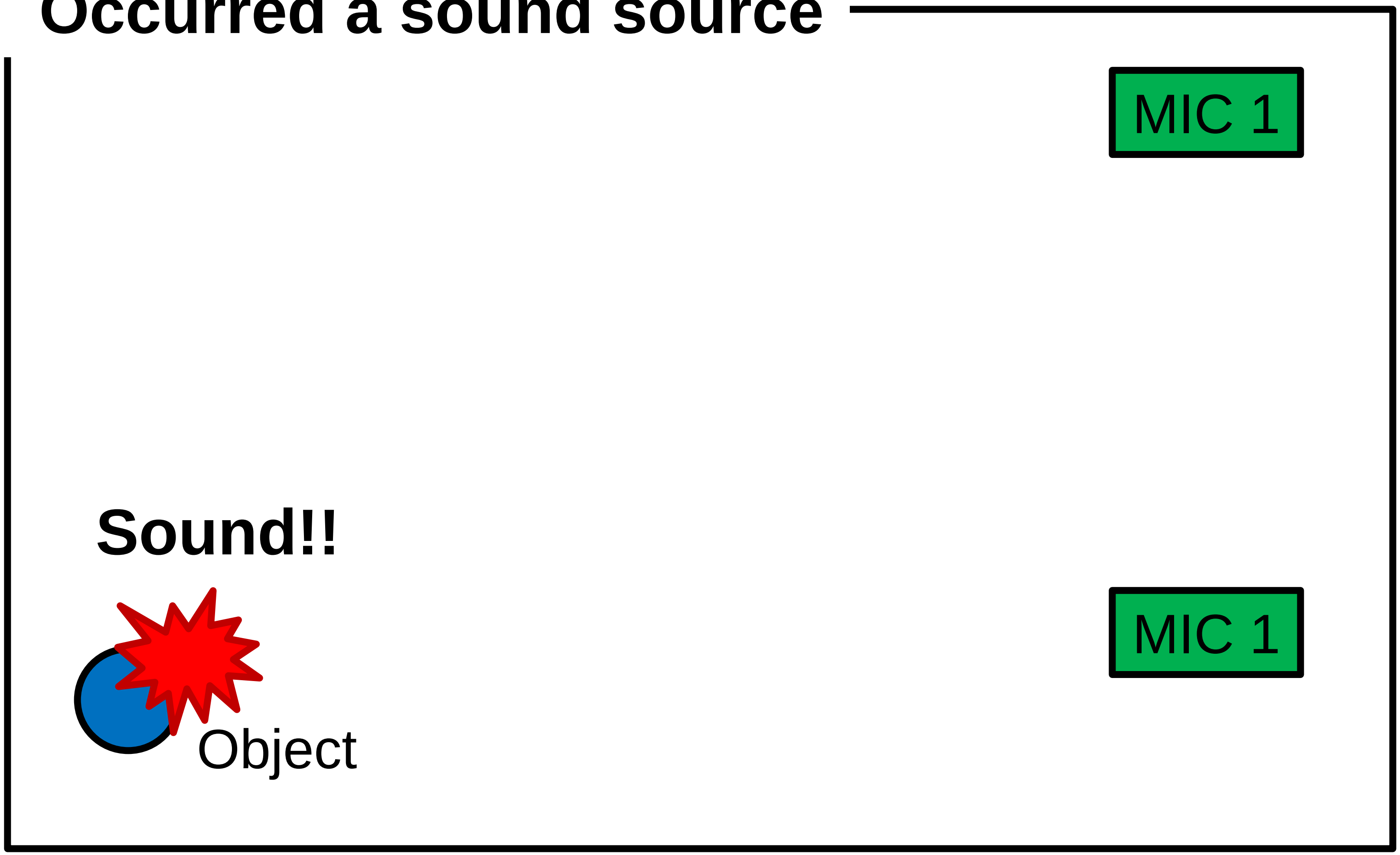
Background | What is the Sound Source Localization ?

2. With S.S.L.

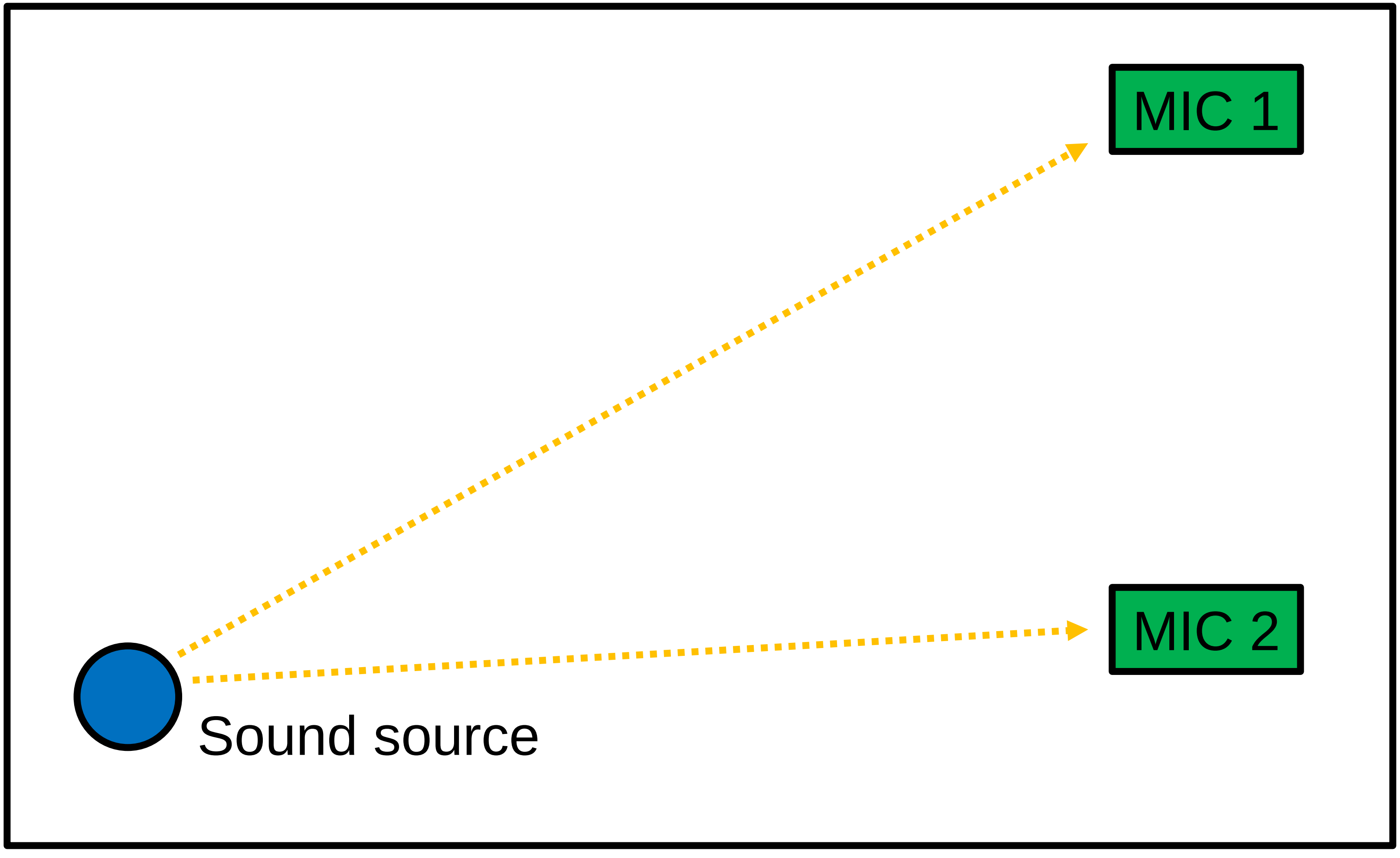


Background | Sound Source Localization

- **Occurred a sound source**



Background | Sound Source Localization



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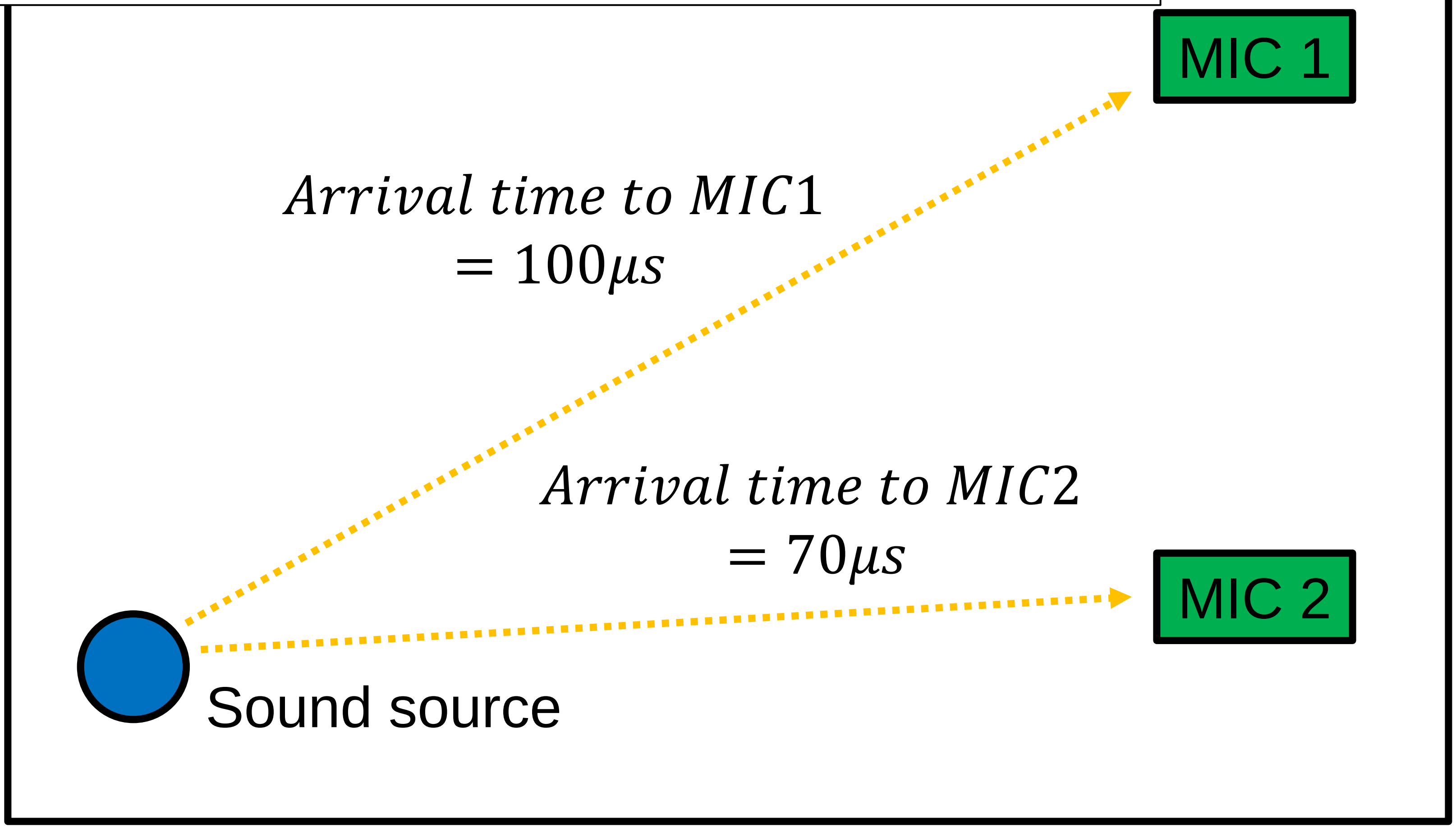
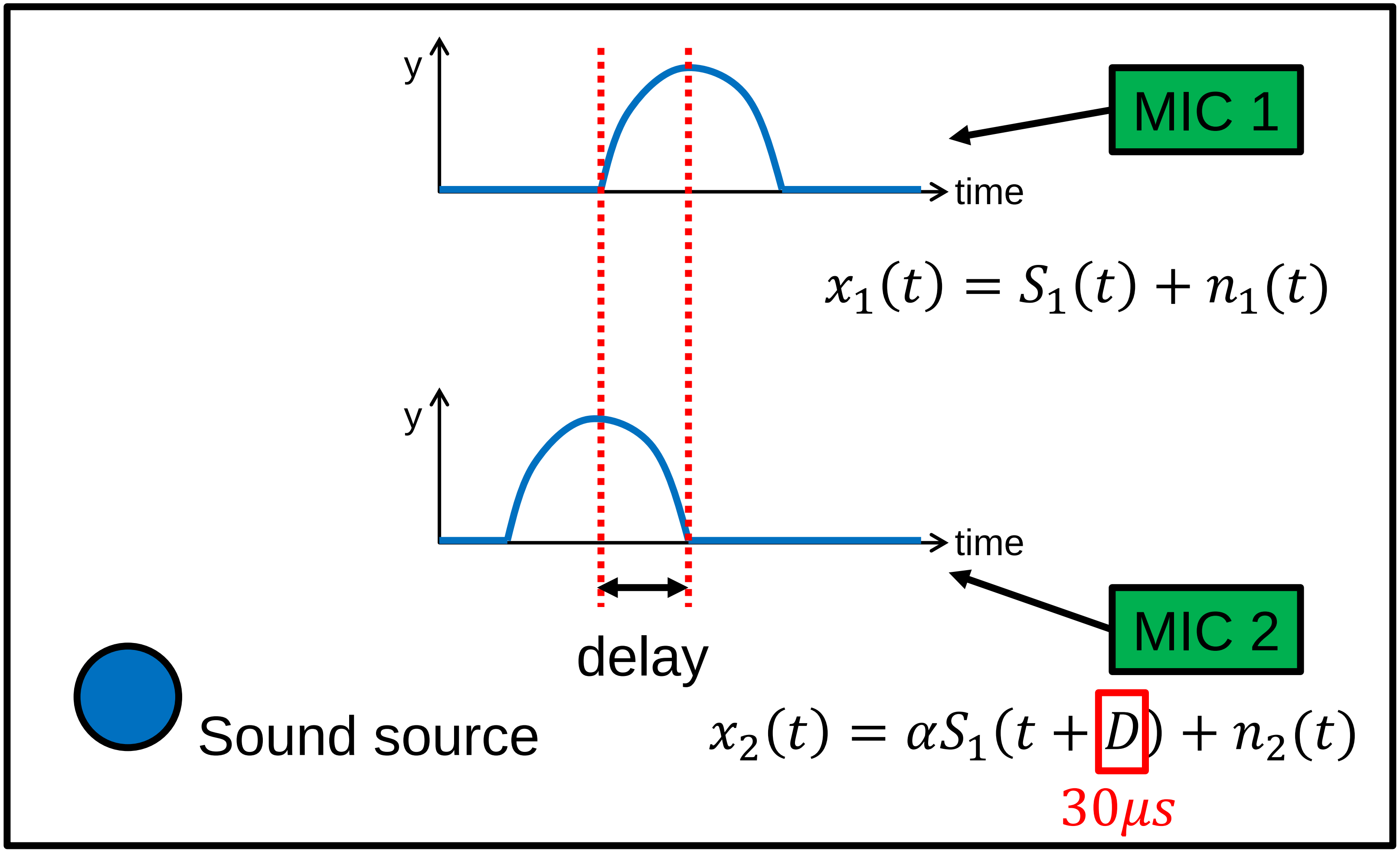
Background | Sound Source Localization

Calculate the difference between arrival times

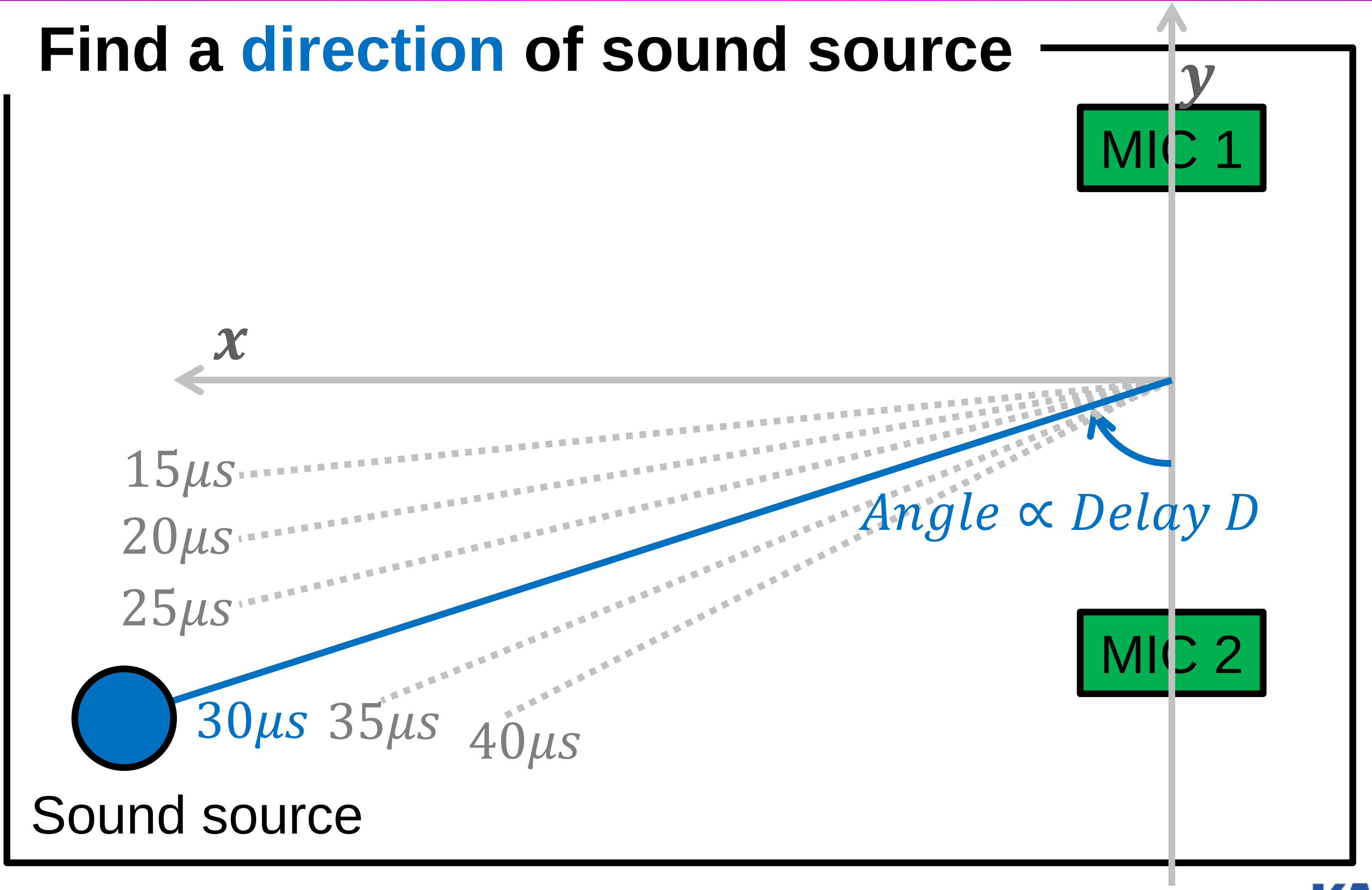


Background | Sound Source Localization



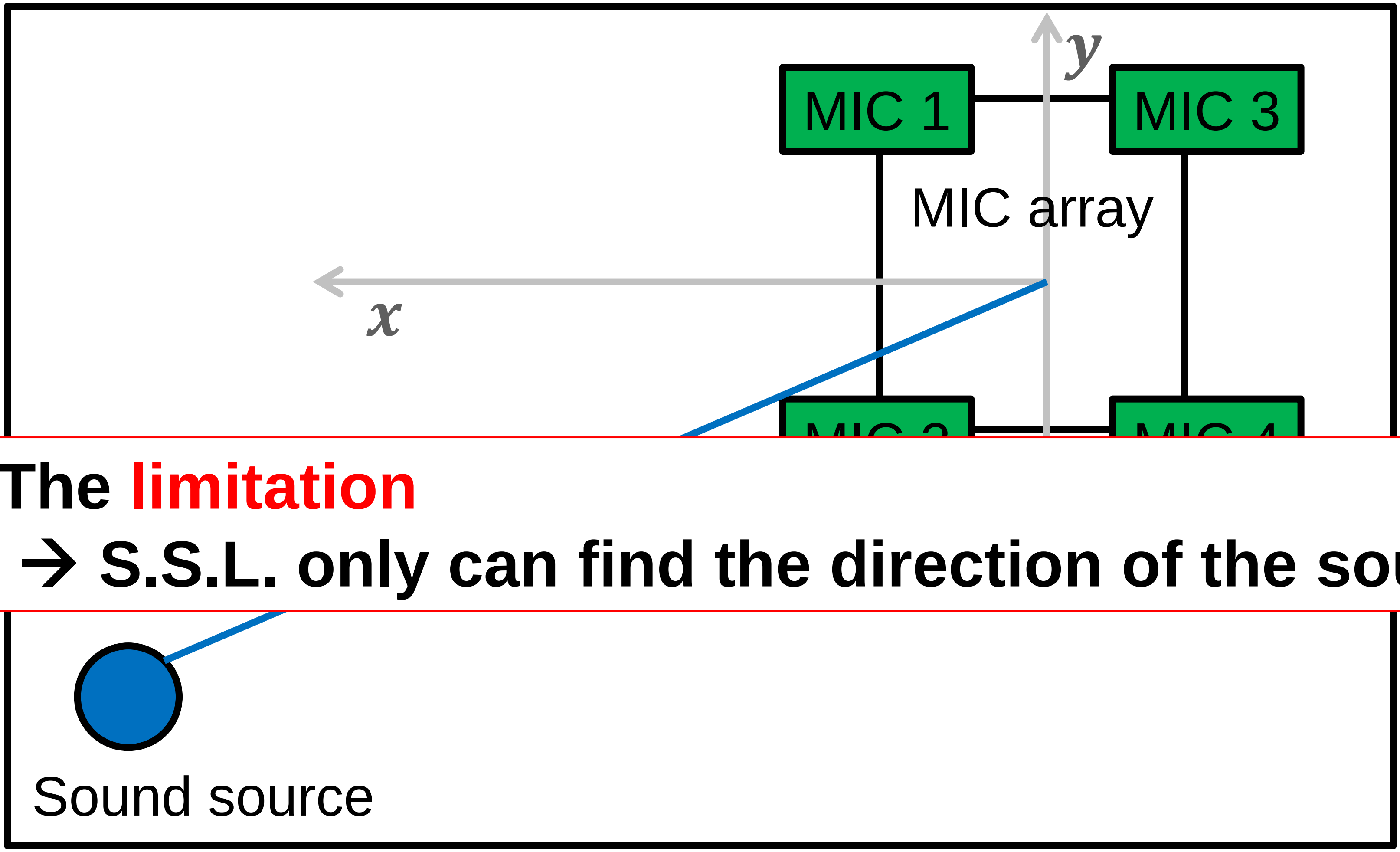
Background | Sound Source Localization

- **Find a direction of sound source**



Content

Motivation | Sound Source Localization



- The **limitation**
  → **S.S.L. only can find the direction of the sound**

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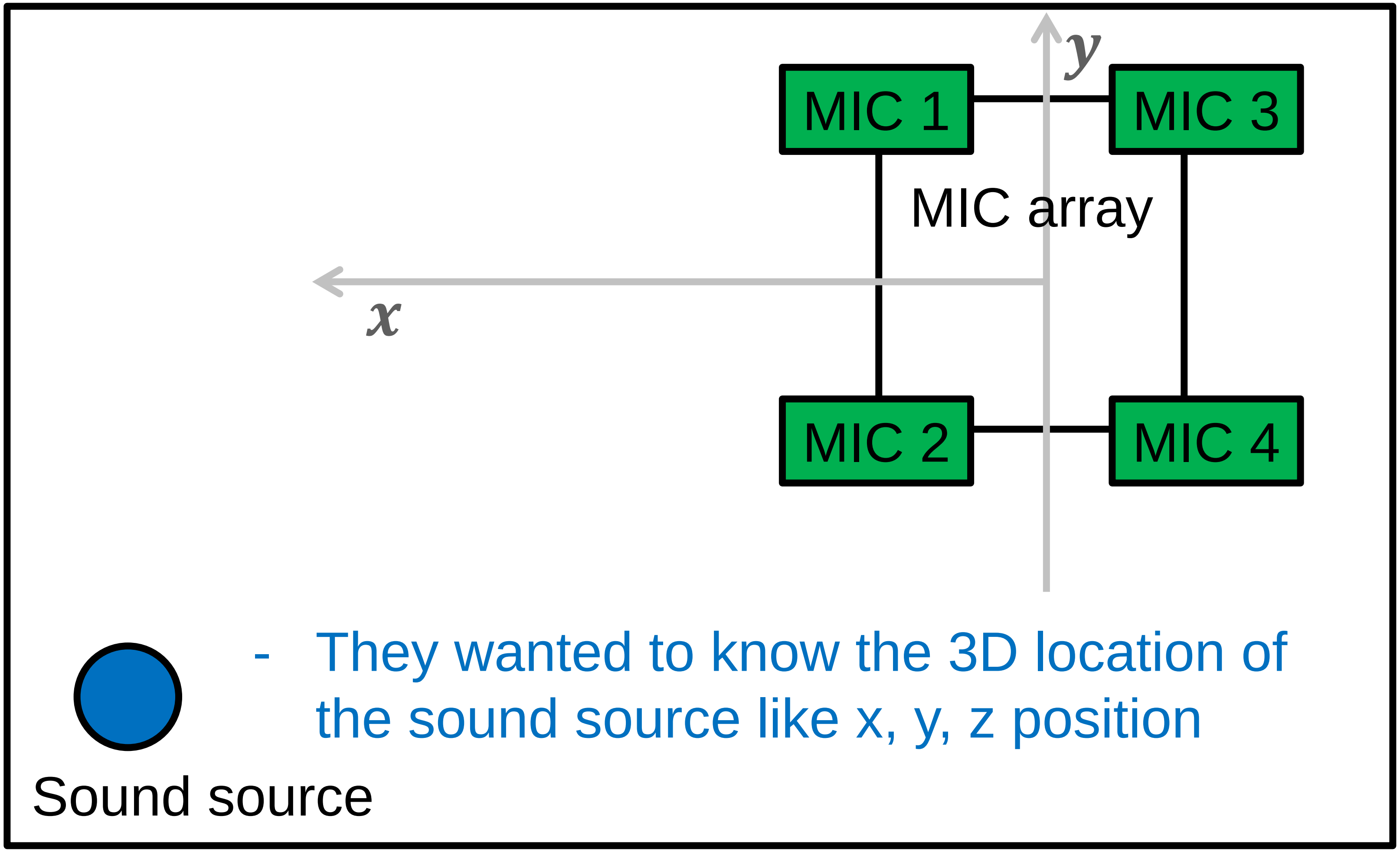
Motivation | Sound Source Localization



- They wanted to know the 3D location of the sound source like x, y, z position

Content

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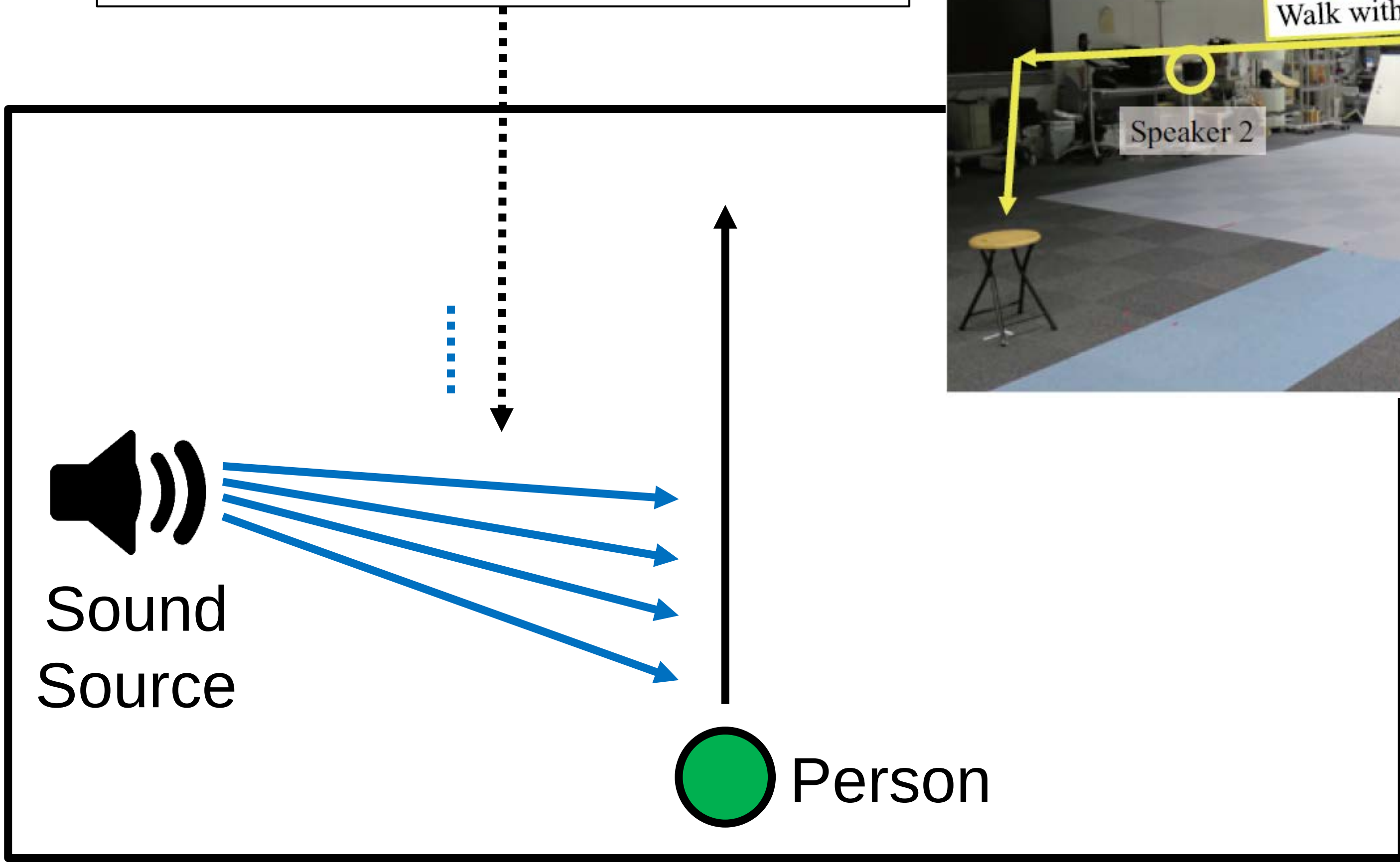
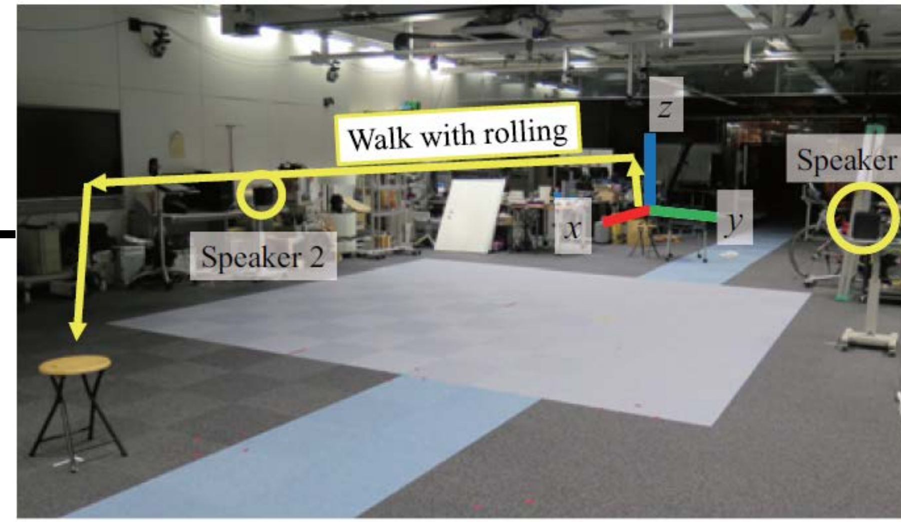
Approach | Probabilistic 3D Sound …

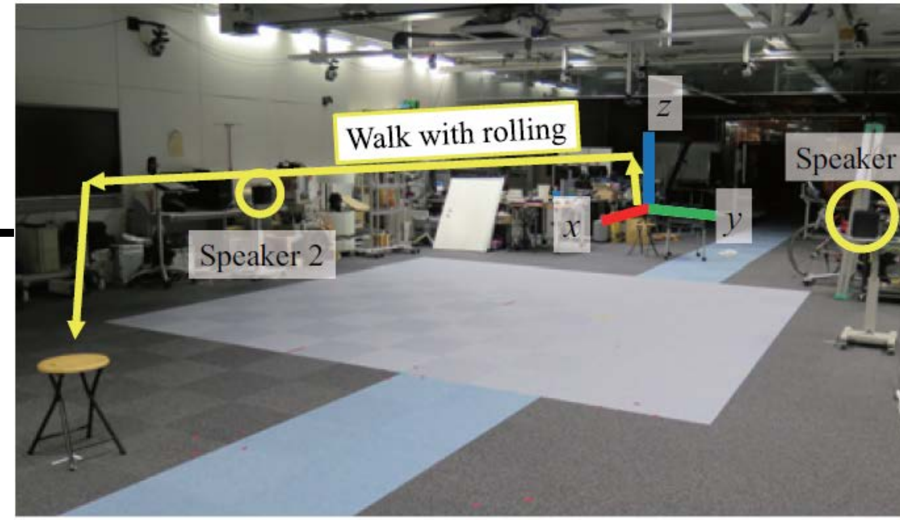
Get directions of sound





Approach | Probabilistic 3D Sound …

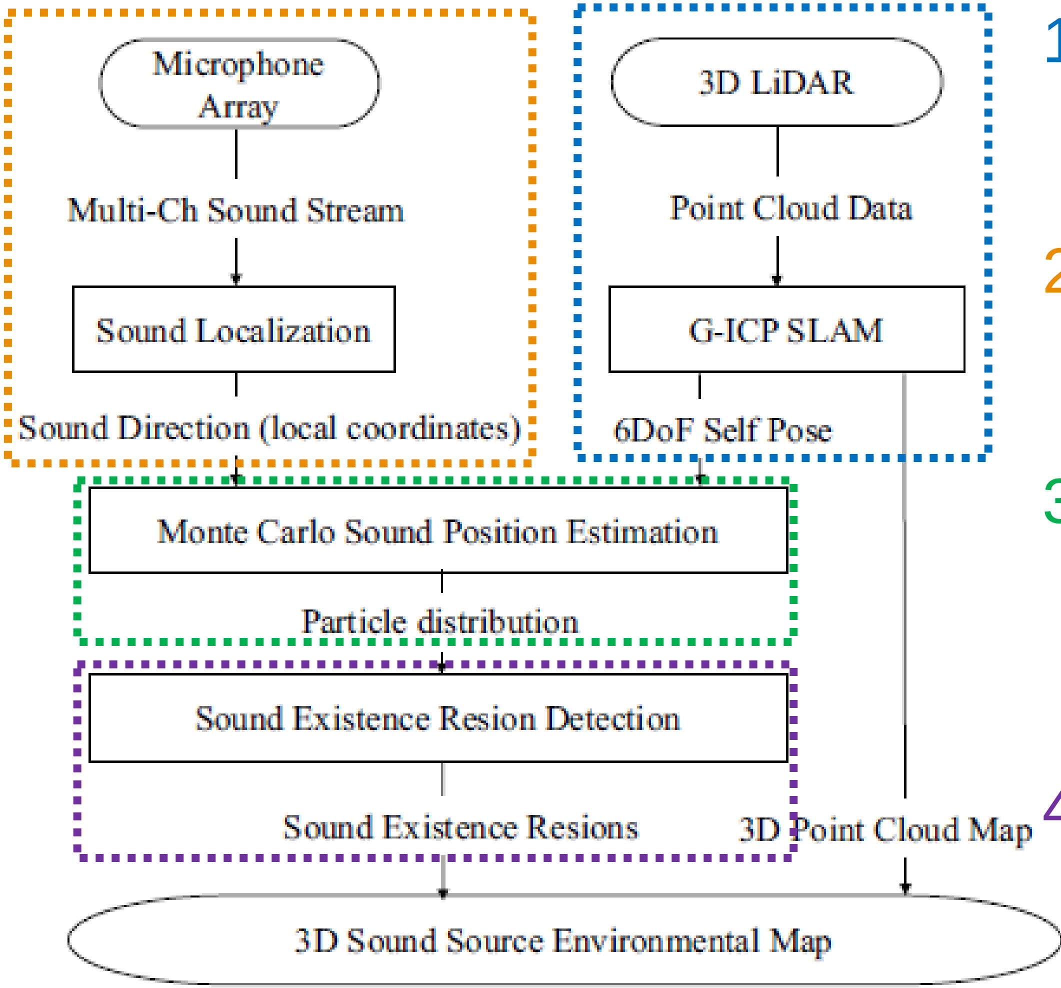
Find the conversion region



< Requirements >

1. Could find the hardware position on the map, when the hardware was moving (held by the person).
2. Detect directions of the sound source while the robot moved.
3. Determine the conversion region.

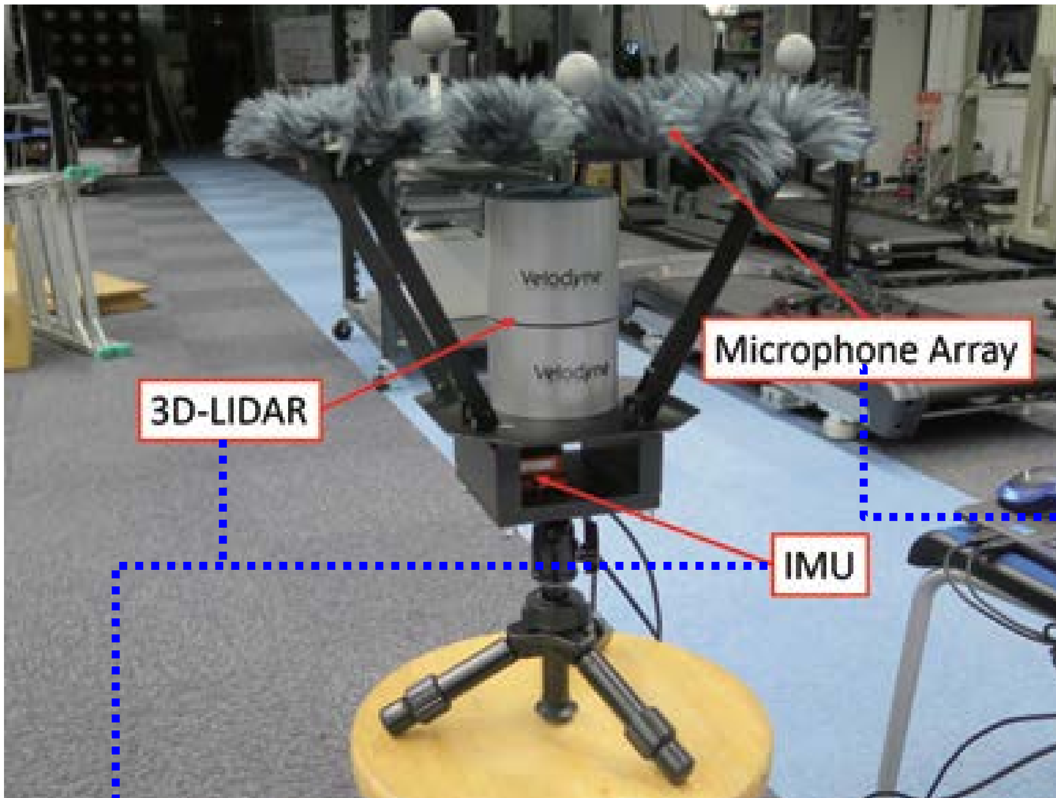
Approach | Probabilistic 3D Sound …



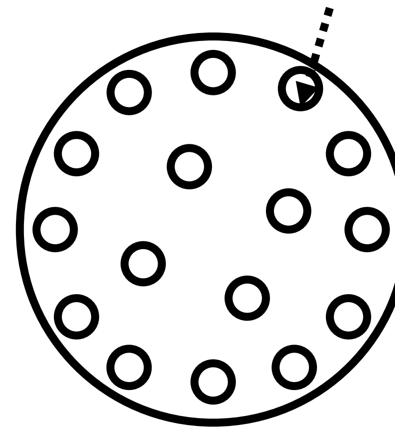
1. SLAM
   → Find the hardware's location in the 3D map
2. Sound Localization
   → Detect the directions of sound
3. Particle Filter
   → Calculate the conversion region of directions
4. Sound Source Region Detection

Related works | Probabilistic 3D Sound …

Hardware (Handheld sensor unit)



MIC

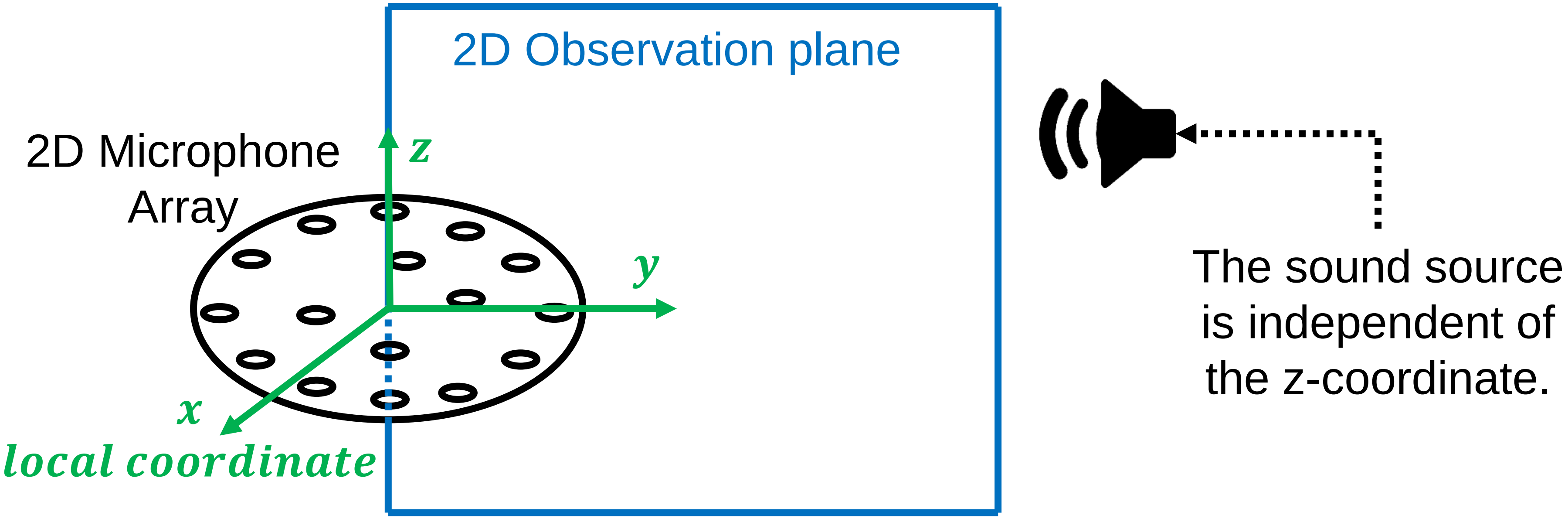


- Detect the directions of sound

- Build the 3D map and find the robot’s position

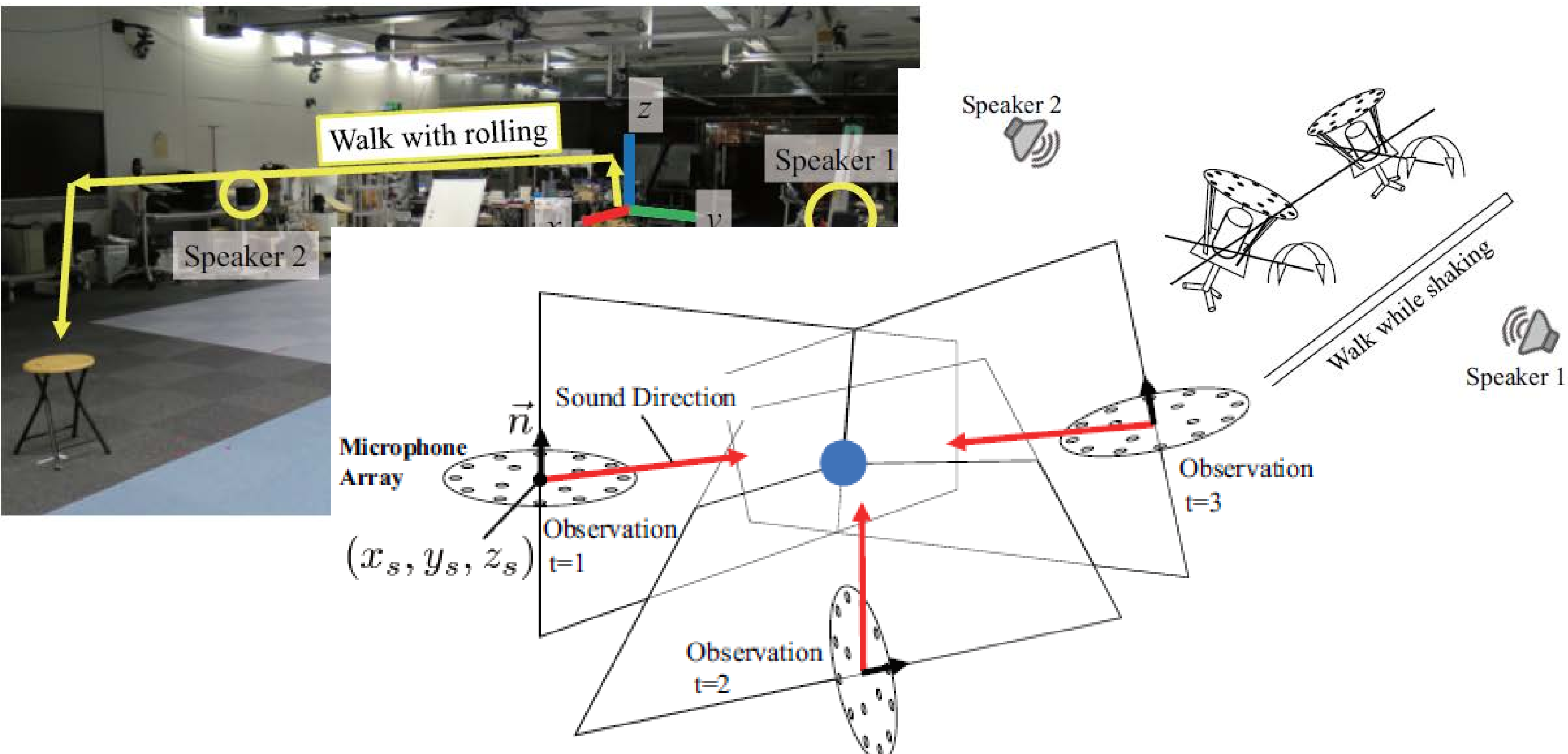
Related works | Probabilistic 3D Sound …

- They could detect 2D observation surfaces with 2D Microphone Array
  = Directions of sound must be contained by 2D observation surface



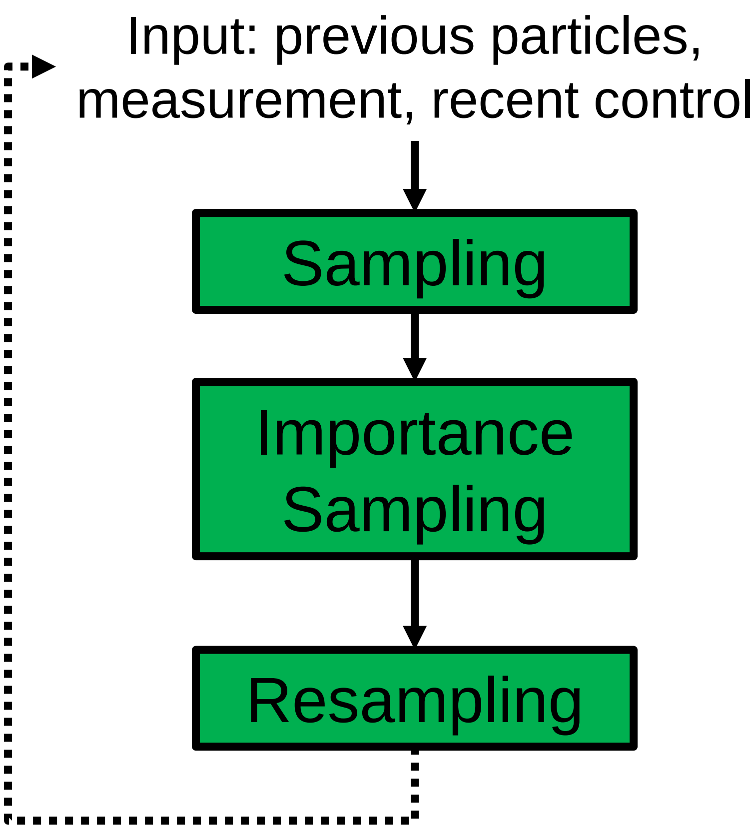
- They accumulated 2D observation surfaces while they moved along the straight line

Related works | Probabilistic 3D Sound …



Related works | Probabilistic 3D Sound …

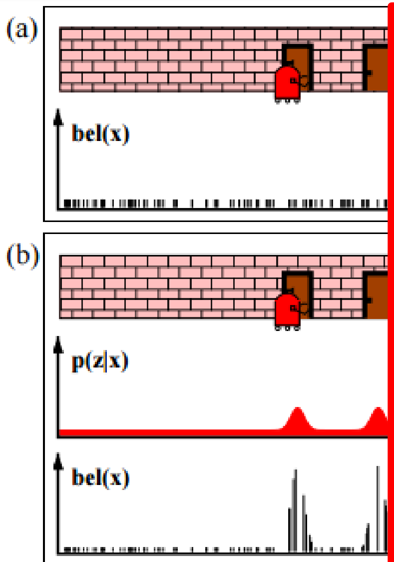
- The particle filters approximate the posterior with particles. (Bayes filter)



- **Sampling** : Sample new particles which are moved by recent control
- **Importance Sampling** : Calculate weights of each particle
- **Resampling** : increase the samples in the high weighted-region, and decrease the samples in the low weighted-region.

Related works | Probabilistic 3D Sound …

- The example of the Particle filter in one-dimensional hallway example (The robot can detect the door)



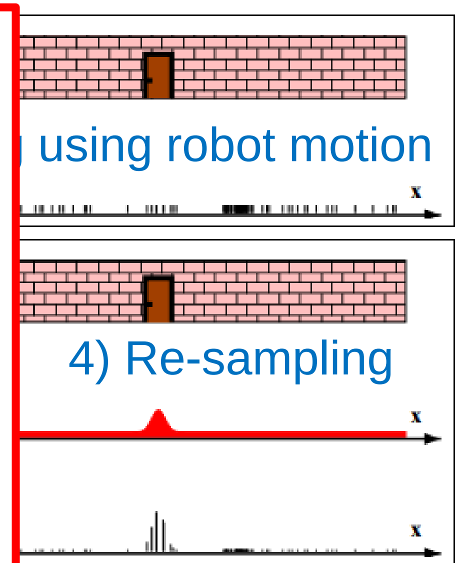
- Distance from the new observation plane

$$d_i = \frac{|ax_{p,i} + by_{p,i} + cz_{p,i} - (ax_o + by_o + cz_o)|}{\sqrt{a^2 + b^2 + c^2}},$$

$$\vec{v} = [a, b, c]^T,$$

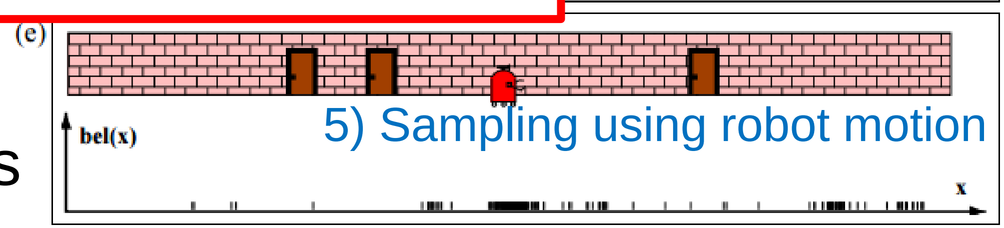
- Weight (Likelihood, $p(o_t|x_t)$)

$$w_i = \frac{1}{\sqrt{2\pi(\sigma'/d_i)}} \exp\left(\frac{d_i^2}{2(\sigma'/d_i)^2}\right).$$



$p(z|x)$: Measurement model

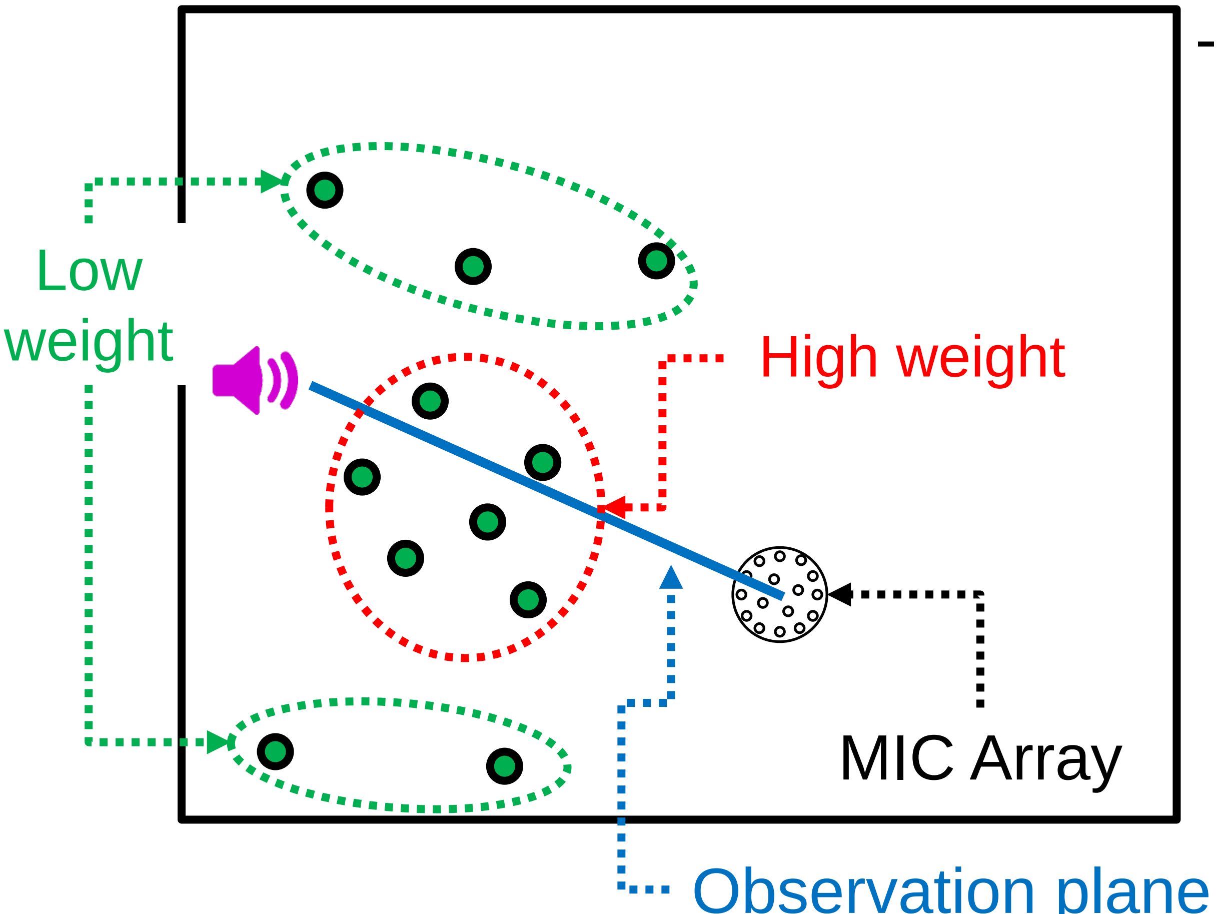
$bel(x)$: Distribution of particles



Referenced by "Probabilistic Robotics"

Related works | Probabilistic 3D Sound …

2D map (Top view)



- Sampling particles using the sound model $p(x_t|x_{t-1})$.

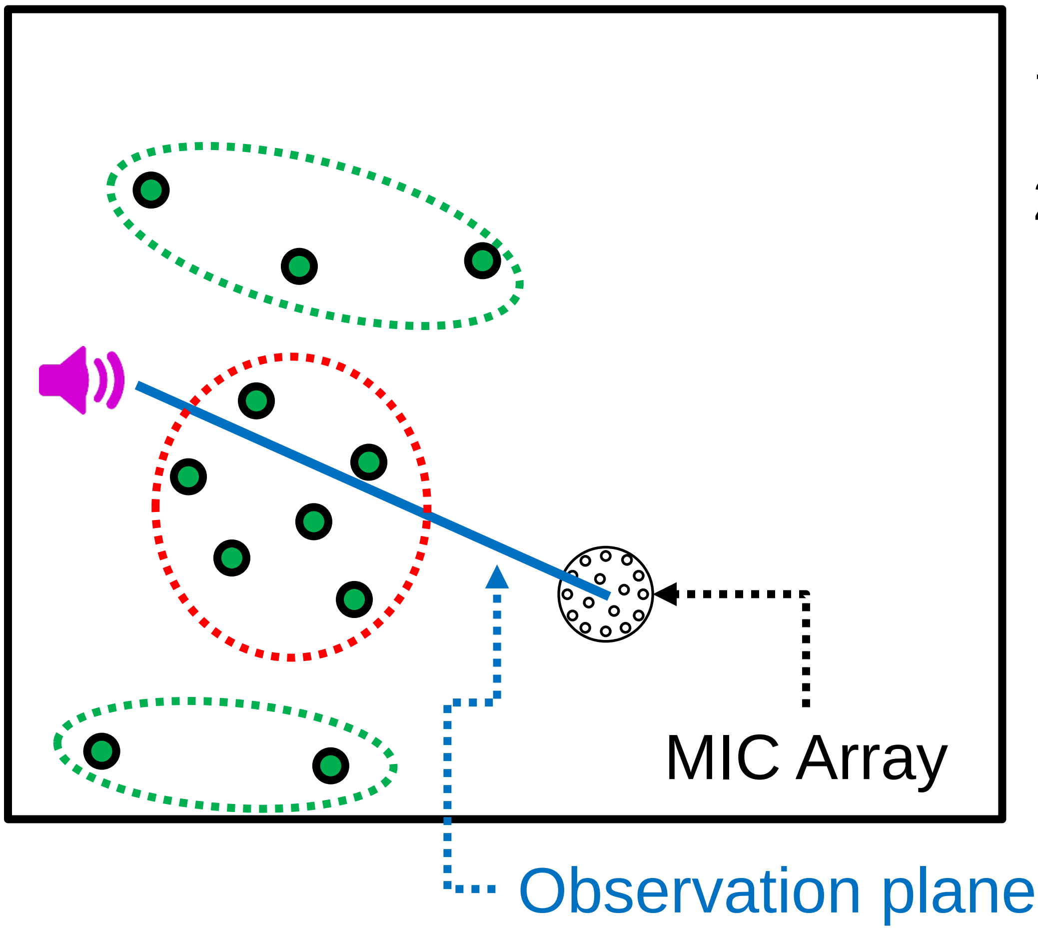
( ) : particles

( ) : Sound source

( ) : MIC Array

Related works | Probabilistic 3D Sound …

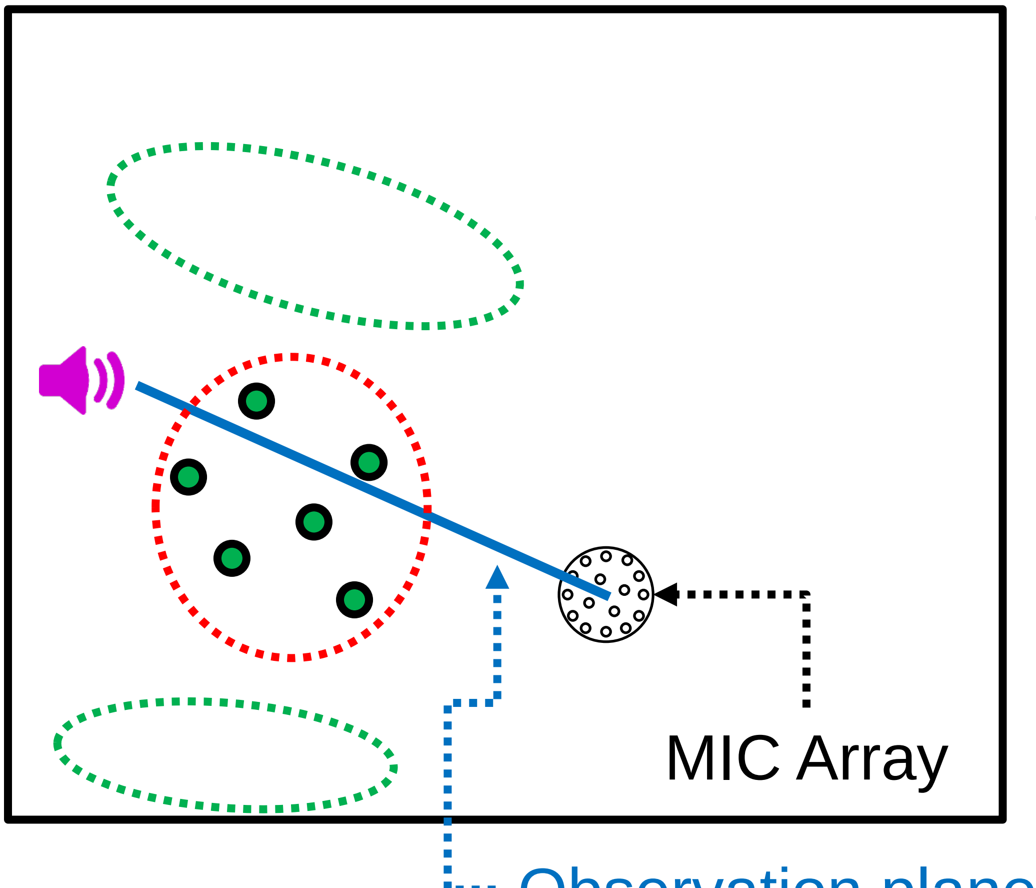
2D map (Top view)



1. Delete low weighted-particles
2. Add particles in the high weighted-region, and reduce the weight

Related works | Probabilistic 3D Sound …

2D map (Top view)



1. Delete low weighted-particles
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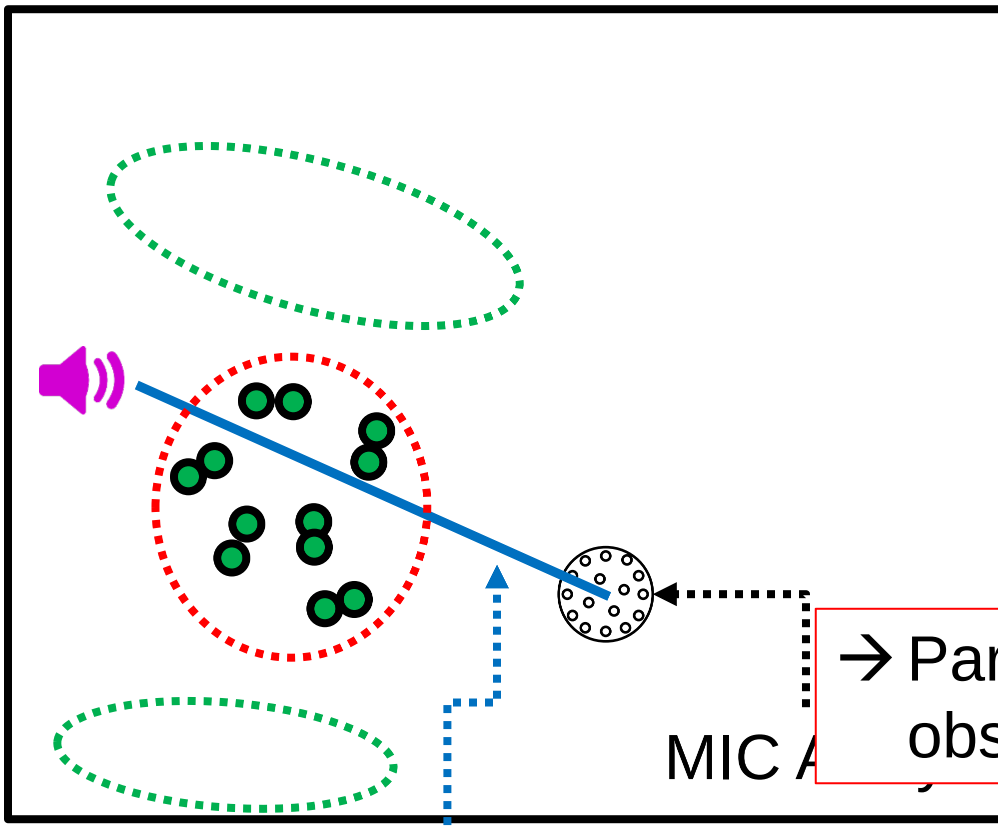
Related works | Probabilistic 3D Sound …

2D map (Top view)



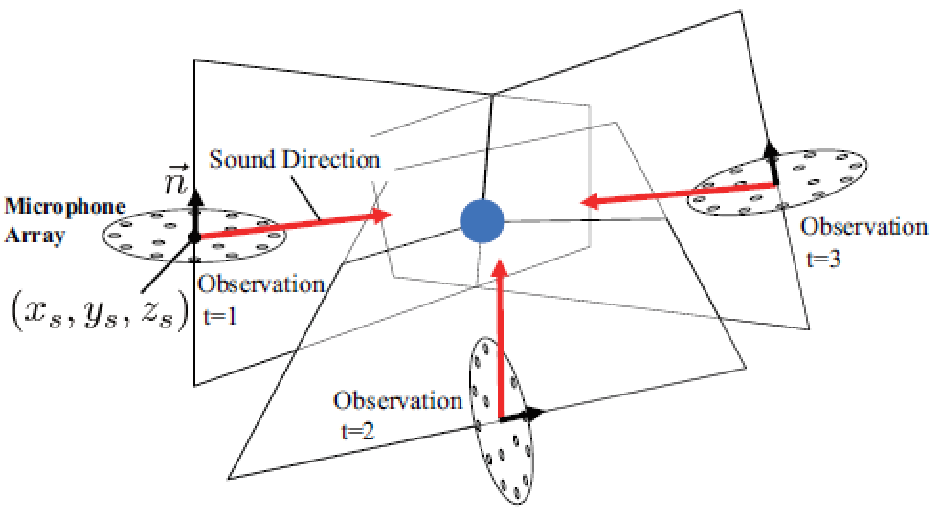
Observation plane

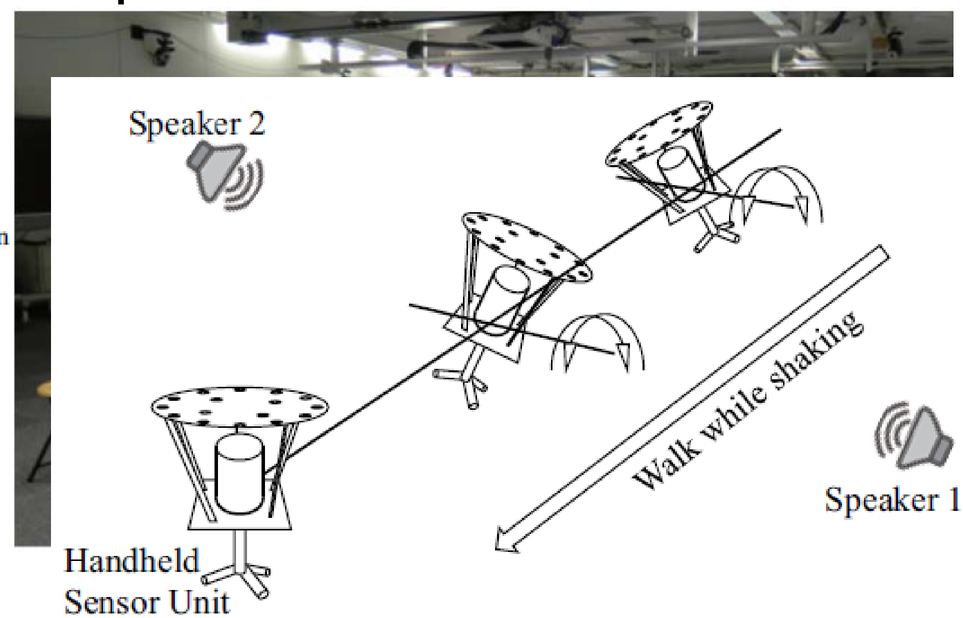
1. Delete low weighted-particles
2. Add particles in the high weighted-region, and reduce the weight (The number of particles has to be same)

→ Particles gather along the observation plane

Related works | Probabilistic 3D Sound …

- They collected **the observation planes** for walking at each frame.
- If they don't walk, They couldn't get the conversion point.
- Also, If they don't shake the hardware during the walking, They couldn't get the conversion point





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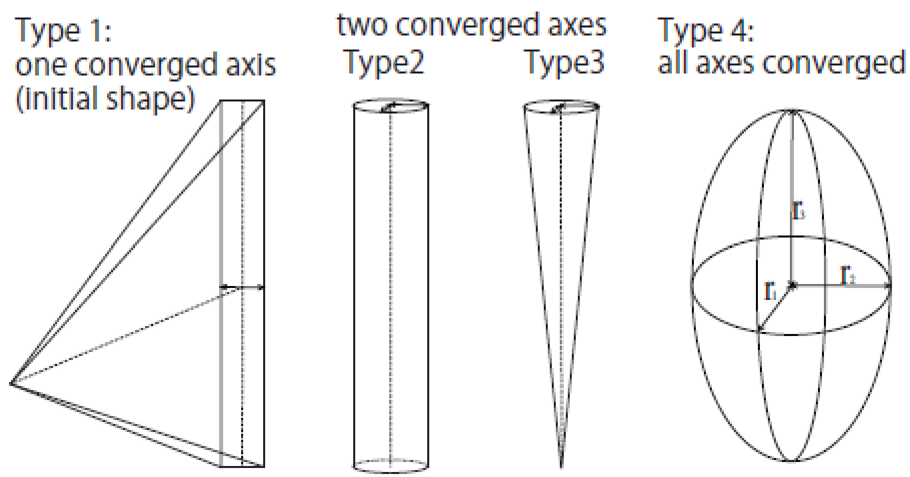
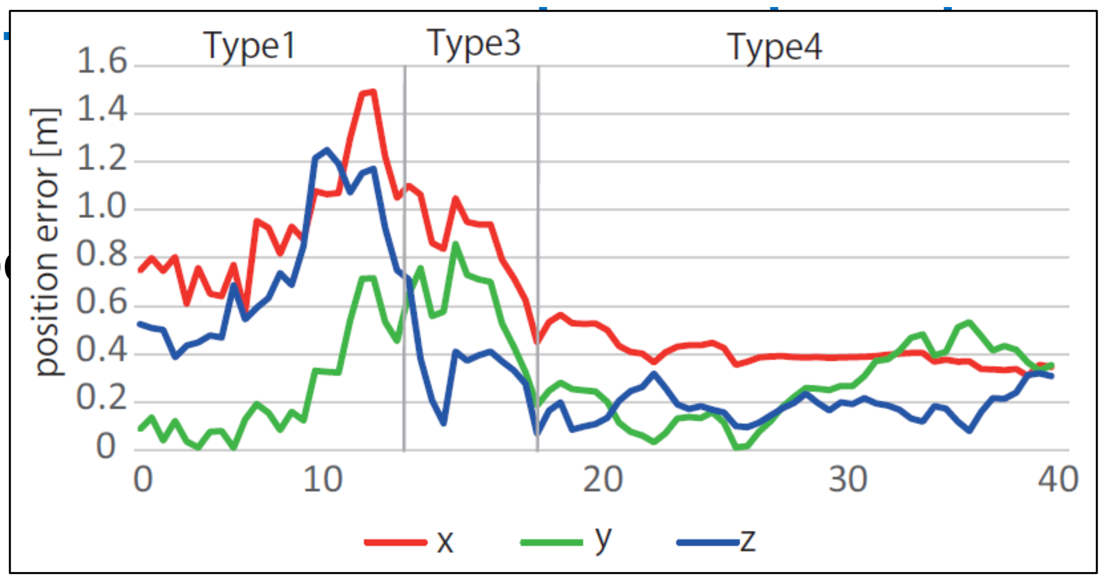
Result | Probabilistic 3D Sound …

- There are four existence regions

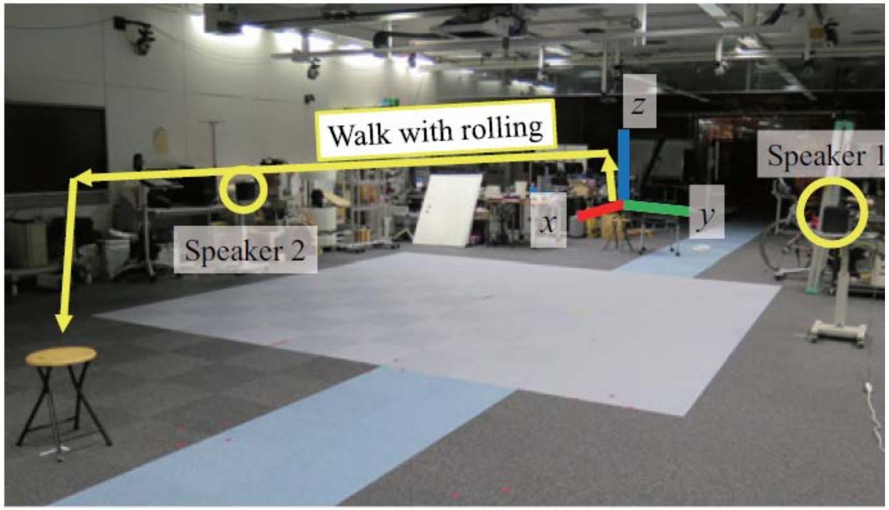


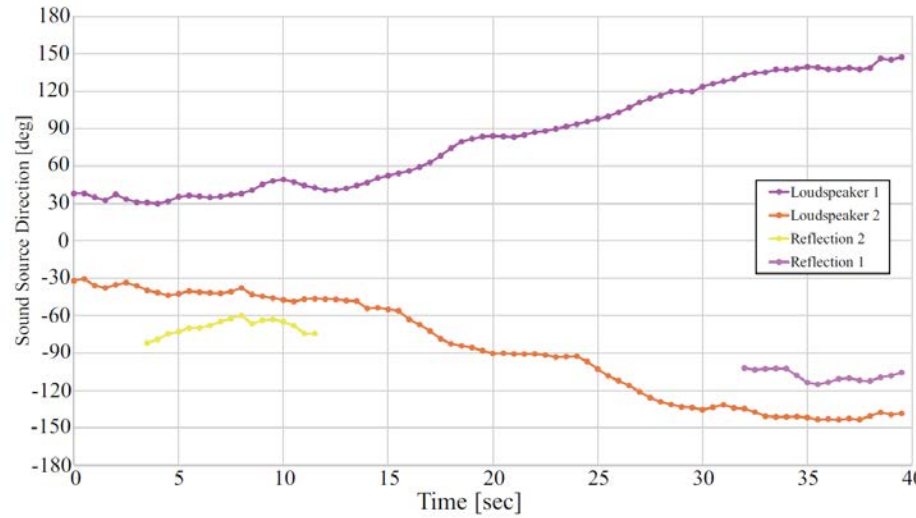


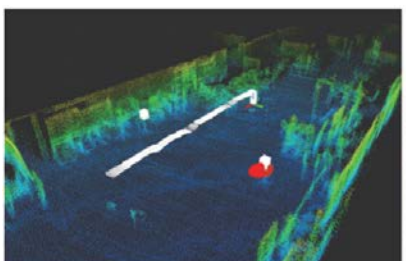
Type 1:
Initial shape
(no shaking, walking)

Type 4:
All axes converged
(shaking, walking)

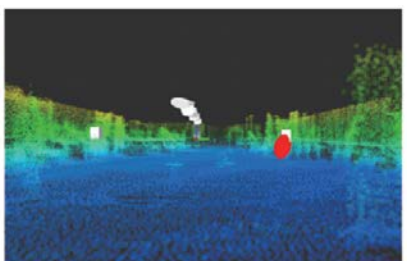
Result | Probabilistic 3D Sound …





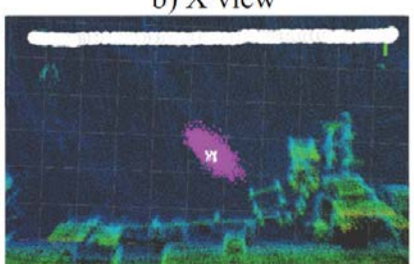


a) Overview

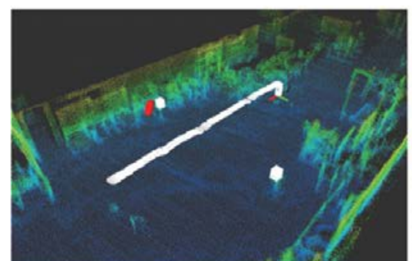


b) X view

c) Y view



d) Z view (particle distribution)



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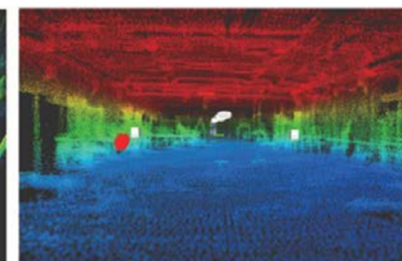
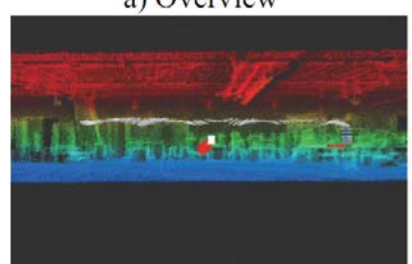
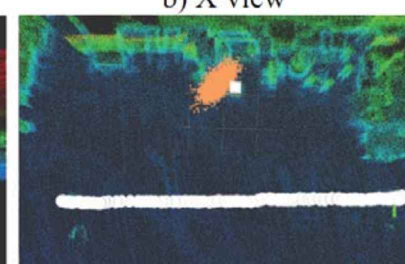


b) X view



c) Y view



d) Z view (particle distribution)

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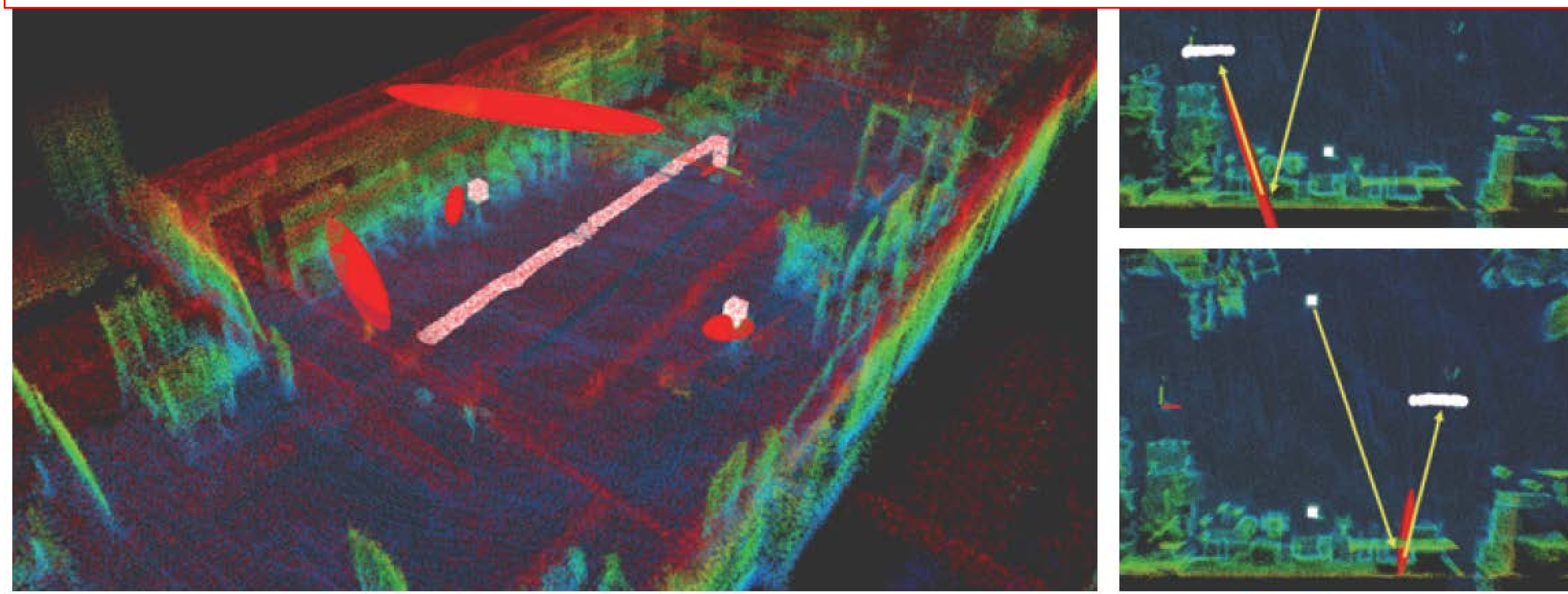
Related works | Probabilistic 3D Sound …

<limitations of this paper>

1) **The robot has to moving and shaking while detecting a sound position.**
2) **Reflections sometimes could be detected.**



a) Overview b) Reflections

Q&A |

Thank you for your attention