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

1. Without S.S.L.

Hey, R2D2
Give me water!

Where are you?
Background | What is the Sound Source Localization?

2. With S.S.L.

Hey, R2D2
Give me water!

Let's compute the Sound Source Localization
Background | What is the Sound Source Localization?

2. With S.S.L.

Hey, R2D2
Give me water!

OK, I’ll get it to you!
Background | Sound Source Localization

- Occurred a sound source
Background | Sound Source Localization

Sound source

MIC 1

MIC 2
Calculate the difference between arrival times

arrival time to MIC1 = 100µs

arrival time to MIC2 = 70µs
Background | Sound Source Localization

\[ x_1(t) = S_1(t) + n_1(t) \]

\[ x_2(t) = \alpha S_1(t + D) + n_2(t) \]

\( 30 \mu s \)
Background | Sound Source Localization

• Find a direction of sound source

\[ \text{Sound source} \]

\[ x \]

\[ y \]

\[ 15\mu s \]
\[ 20\mu s \]
\[ 25\mu s \]
\[ 30\mu s \]
\[ 35\mu s \]
\[ 40\mu s \]

\[ \text{MIC 1} \]

\[ \text{MIC 2} \]

\[ \text{Angle } \propto \text{ Delay } D \]
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Motivation | Sound Source Localization

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

Sound source
Motivation | Sound Source Localization

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

Sound source
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Approach | Probabilistic 3D Sound ...

Get directions of sound

Sound Source

Person
**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)

- 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

The sound source is independent of the z-coordinate.
Related works | Probabilistic 3D Sound ...
Related works | Probabilistic 3D Sound ...

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

  Input: previous particles, measurement, recent control

  - **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)

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

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

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

- Distance from the new observation plane
- Weight (Likelihood, \( p(o_t | x_t) \))

\( p(z|x) \): 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 \( p(\mathbf{x}_t | \mathbf{x}_{t-1}) \).

(○) : particles  
(-speaker icon) : Sound source  
(⊙) : MIC Array  

Low weight  
High weight  
Observation plane
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

MIC Array

Observation plane
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

Observation plane
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 (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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- There are four existence regions

Type 1: Initial shape (no shaking, no walking)

Type 2: Two converged axes (no shaking, walking)

Type 3: Two converged axes (shaking, no walking)

Type 4: All axes converged (shaking, walking)
Result | Probabilistic 3D Sound ...
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<limitations of this paper>

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

Thank you for your attention