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# Microphone Array Position Self-Calibration from Reverberant Speech Input

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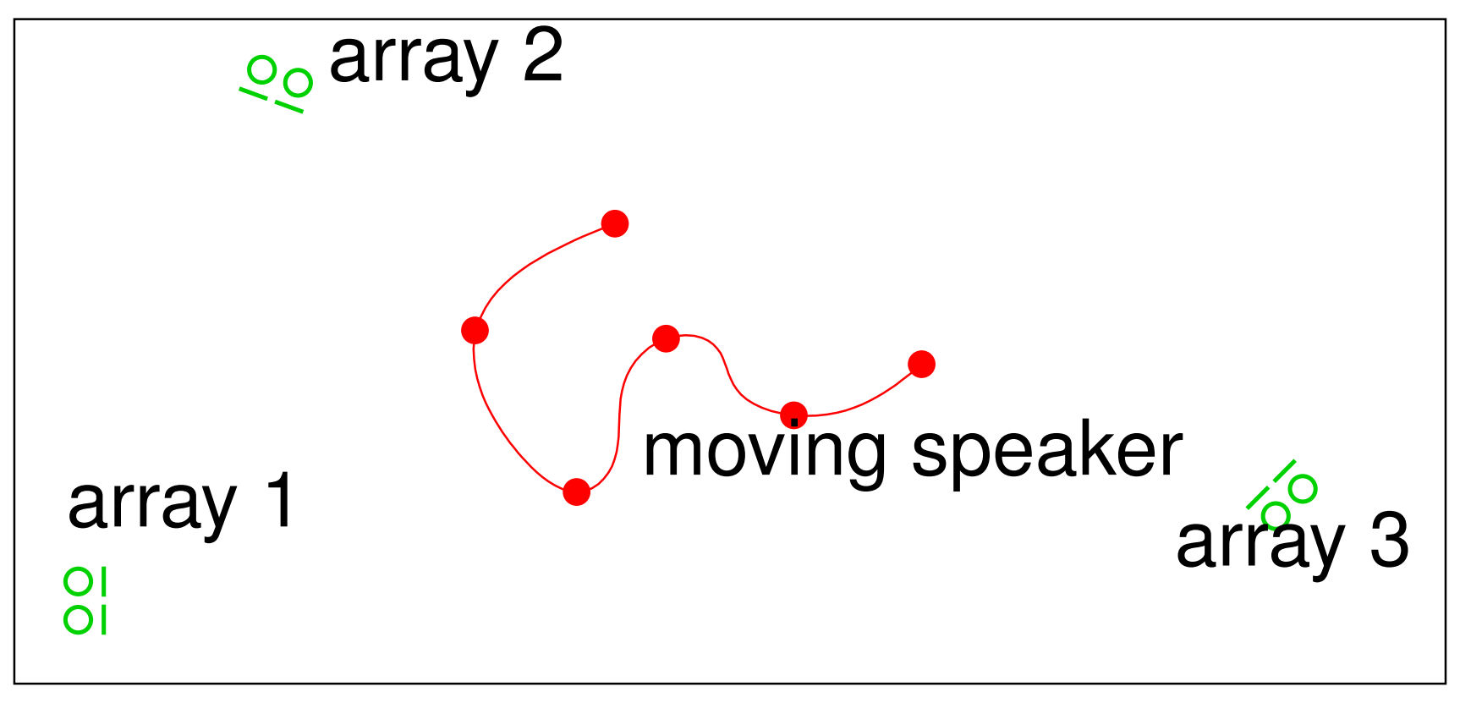
## Introduction

- The geometry of an acoustic sensor network is required for many signal processing applications
- Automatic sensor position estimation preferable to error-prone manual measurement process
- Existing approaches often use artificial calibration signals or special hardware to achieve high positioning accuracy
- Goal: Relative geometry calibration based on reverberant speech input

## Problem statement (2D)

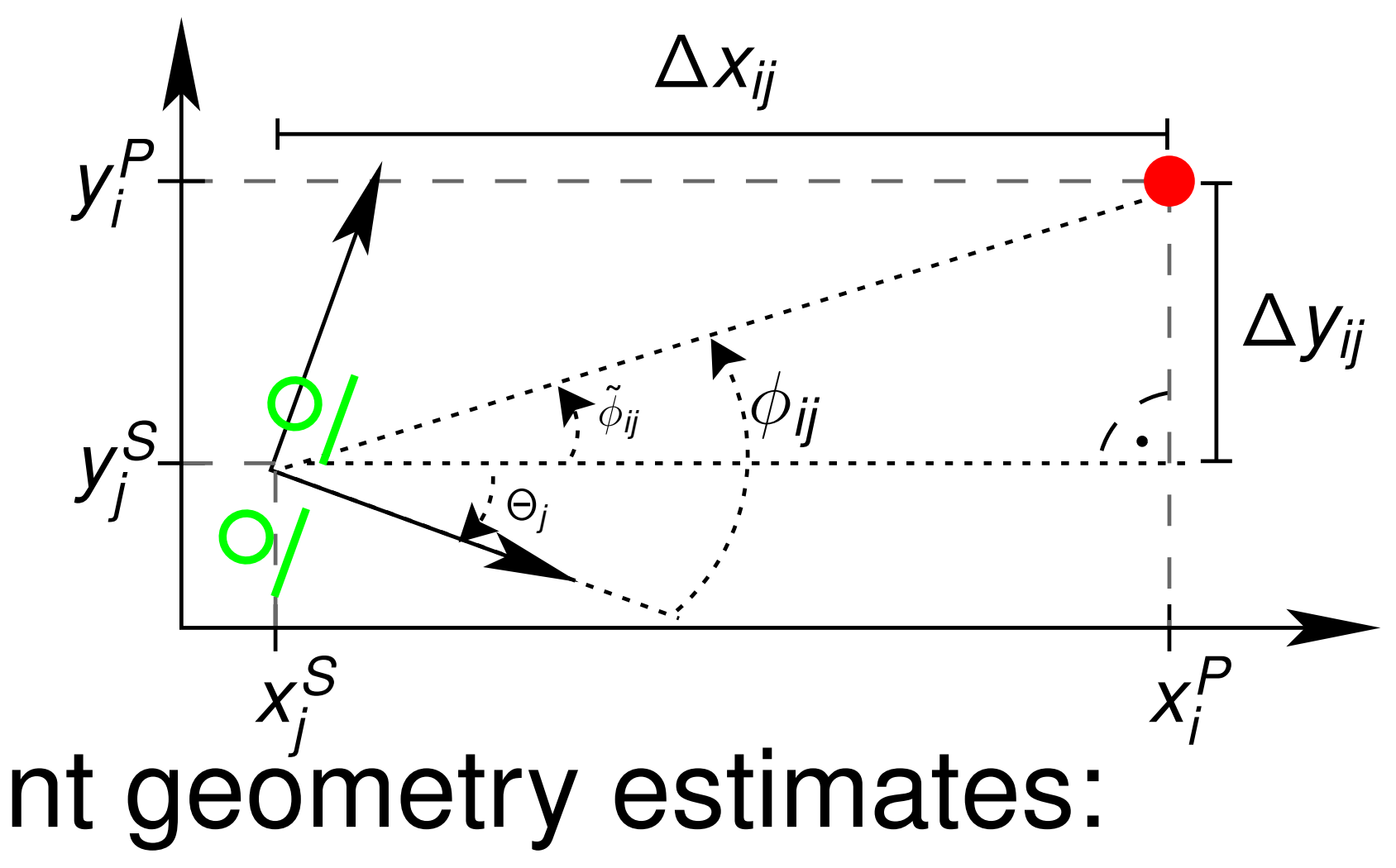
- Each sensor node consists of a microphone array
- Array configuration within sensor node known
- Measurements: Direction of Arrival (DoA) from each sensor node
- Unknown parameters:
  - Sensor positions: $[x_j^S, y_j^S]$
  - Sensor orientations: $\Theta_j$
  - Speaker positions: $[x_i^P, y_i^P]$



## Proposed cost function

- $\phi_{ij}$: DoA of *i*-th speaker position measured by *j*-th sensor:

$$\boldsymbol{v}_{ij} = \left[\cos\left(\phi_{ij}\right)\ \sin\left(\phi_{ij}\right)\right]^T$$



- DoA vector predicted by current geometry estimates:

$$\tilde{\boldsymbol{v}}_{ij} = \begin{bmatrix}\cos\left(\tilde{\phi}_{ij}-\widehat{\Theta}_j\right)\\ \sin\left(\tilde{\phi}_{ij}-\widehat{\Theta}_j\right)\end{bmatrix} = \underbrace{\begin{bmatrix}\cos\left(\widehat{\Theta}_j\right) & \sin\left(\widehat{\Theta}_j\right)\\ -\sin\left(\widehat{\Theta}_j\right) & \cos\left(\widehat{\Theta}_j\right)\end{bmatrix}}_{\boldsymbol{R}(-\widehat{\Theta}_j)} \underbrace{\frac{1}{\sqrt{\widehat{\Delta x}_{ij}^2+\widehat{\Delta y}_{ij}^2}}}_{1/|\widehat{\boldsymbol{v}}_{ij}|} \underbrace{\begin{bmatrix}\widehat{\Delta x}_{ij}\\ \widehat{\Delta y}_{ij}\end{bmatrix}}_{\widehat{\boldsymbol{v}}_{ij}}$$

- Cost function:

$$J_C = \sum_{i=1}^{N}\sum_{j=1}^{K} \underbrace{\left\{|\widehat{\boldsymbol{v}}_{ij}|\left[1-\cos\left(\sphericalangle\left(\boldsymbol{v}_{ij}, \tilde{\boldsymbol{v}}_{ij}\right)\right)\right]\right\}^2}_{g_{ij}}$$

- Iterative cost function minimization using Newton's method gives estimates: $[\widehat{x}_i^S, \widehat{y}_i^S, \widehat{\theta}_j, \widehat{x}_j^P, \widehat{y}_j^P]$

## Previous cost function

- Geometric relation between sensor and observation:

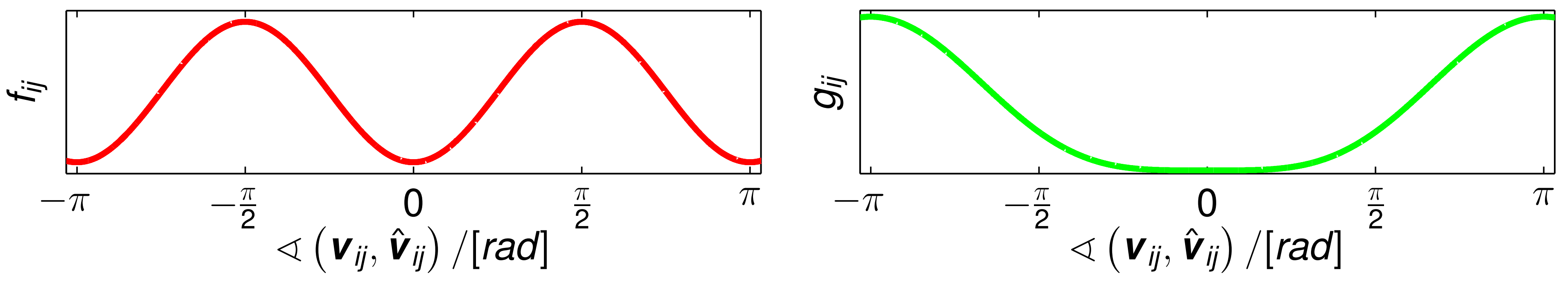
$$\tan\left(\widehat{\Theta}_j + \phi_{ij}\right) = \frac{\sin\left(\widehat{\Theta}_j+\phi_{ij}\right)}{\cos\left(\widehat{\Theta}_j+\phi_{ij}\right)} = \frac{\widehat{\Delta y}_{ij}}{\widehat{\Delta x}_{ij}}$$

- Resulting cost function

$$J_S = \sum_{i=1}^{N}\sum_{j=1}^{K} \underbrace{\left\{|\widehat{\boldsymbol{v}}_{ij}|\sin\left(\sphericalangle\left(\boldsymbol{v}_{ij}, \widehat{\boldsymbol{v}}_{ij}\right)\right)\right\}^2}_{f_{ij}}$$

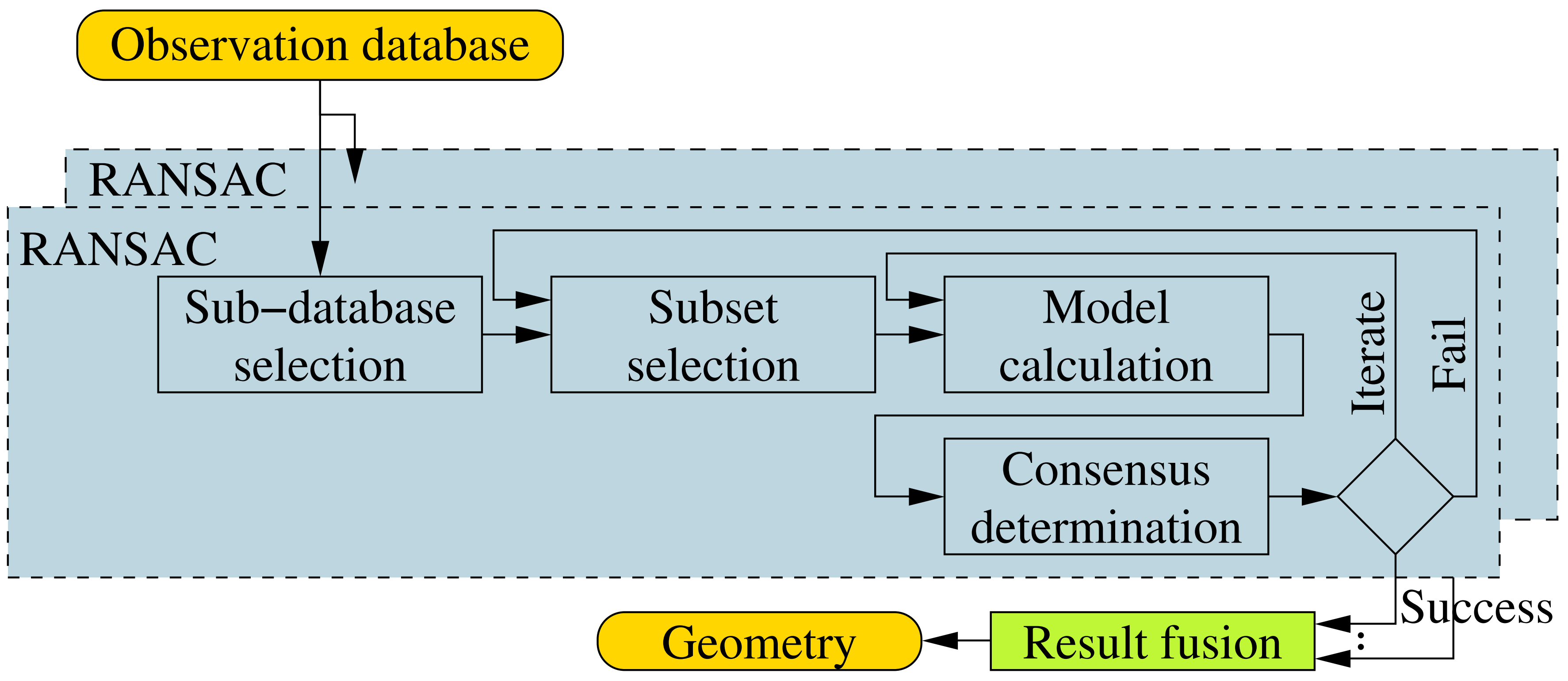
## Comparison

- Previous cost function: Local minima, that correspond to wrong sensor orientations
- Proposed cost function: Avoids local minima, that correspond to wrong sensor orientations



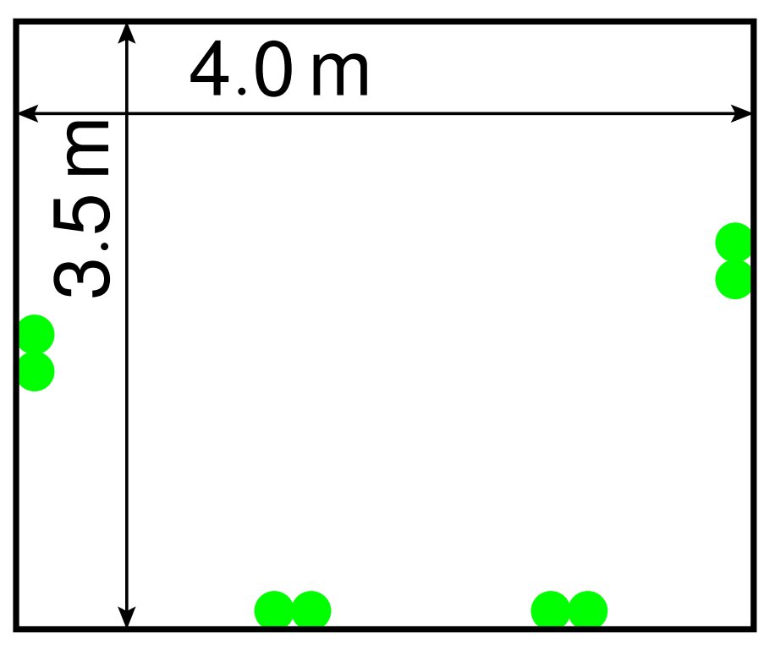
## Random Sample Consensus (RANSAC)

- Precision of automatic geometry calibration highly depends on the quality of the DoA estimates
- Calibration embedded into RANSAC for outlier rejection

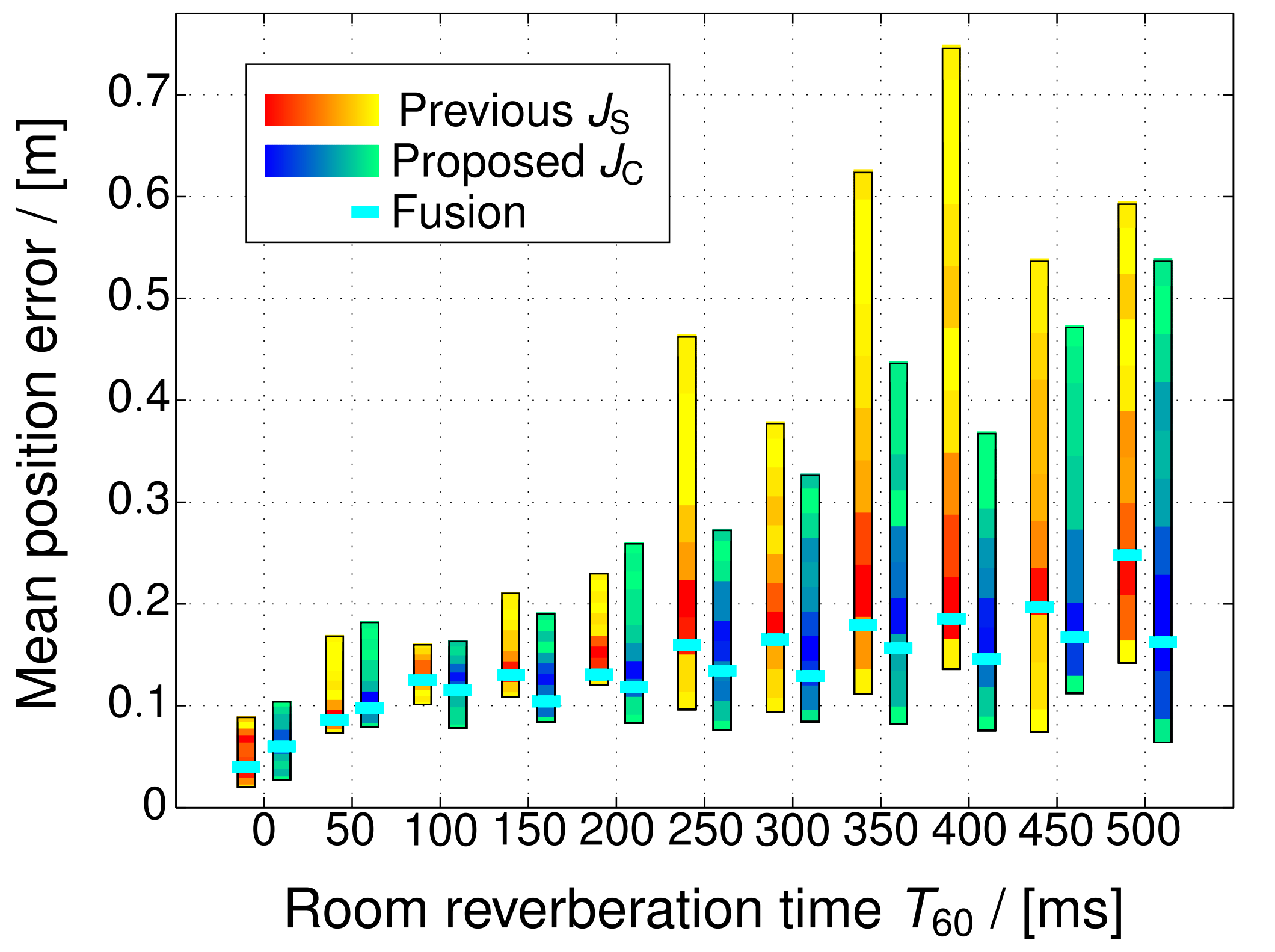

Observation database
RANSAC
RANSAC
Sub–database selection
Subset selection
Model calculation
Consensus determination
Iterate
Fail
Success
Geometry
Result fusion

## Experiments

- Room geometry:



- Simulated audio database, based on image method
- Reverberation times from 0 ms up to 500 ms



Comparison of the mean positioning error between the existing cost function and the proposed cost function for different reverberation times.

## Conclusions

- New formulation avoids solutions that correspond to mirrored sensor orientations
- RANSAC increases robustness against reverberation
- Mean positioning error smaller than 0.25 m for reverberation times up to 500 ms

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