We have developed two localization algorithms: **Methods**

- The **Iterative Cone Alignment** calculates the positions of receivers M and sound sources S. The relation between M and S is described by the signal propagation equation:

  \[ c(t_{M} - t_{S}) = |M - S| \]

  It may be represented by particles residing on cone hulls in \( p+1 \)-dimensional space. An iterative spring-mass simulation implements springs between microphones and the associated sound events. By relaxation of the spring forces the potential energy \( \Phi \) of the particles is optimized. In two-dimensional space at least four microphones and five sound sources are required.

- If only three microphones are available we can still find a solution. The **Ellipsoid TDOA method** [1] shows an elegant closed-form estimation of the distances between triples of receivers. The only assumption is that the sound signals originate from far away.

**Introduction**

We present a localization system for mobile devices relying only on ambient sound signals from unknown positions. No positional anchors are given. By evaluation of the time differences of arrival (TDOA) we can calculate both the positions of smartphones with microphones and ambient sound signals. We synchronize the devices up to an order of 0.1 ms in a wireless network. This results in a positioning precision in the order of 10 cm.

Our approach enables cost-efficient localization in indoor environments and when Global Navigation Satellite Systems (GNSS) are not available.

**Experiments**

Several experiments were performed to explore the performance of the sound localization system. In an outdoor scenario four iPhones and four laptops were arranged in an area of 30 \( \times \) 25 meters on a green field on the campus. Sounds were generated by an assistant clapping two wooden bars at different locations. The localization software got the recorded audio signals as the only input and calculated the relative positions. After congruently mapping the relative positions to the ground-truth an average error of the microphones of only 0.28 m (\( \sigma = 0.14 \) m) remained.

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**References**
