Research Training Group Embedded Microsystems
Project D.2

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TDOA Self-Localization based on Ambient Sound Signals

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 smart-phones 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.

Methods

We have developed two localization algorithms:

- 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:

  $$c\,(t_{\mathrm{M,S}} - t_{\mathrm{S}}) = \| \mathrm{M} - \mathrm{S} \|$$

  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 Φ of the particles is optimized. In two-dimensional space at least four microphones and five sound sources are required.

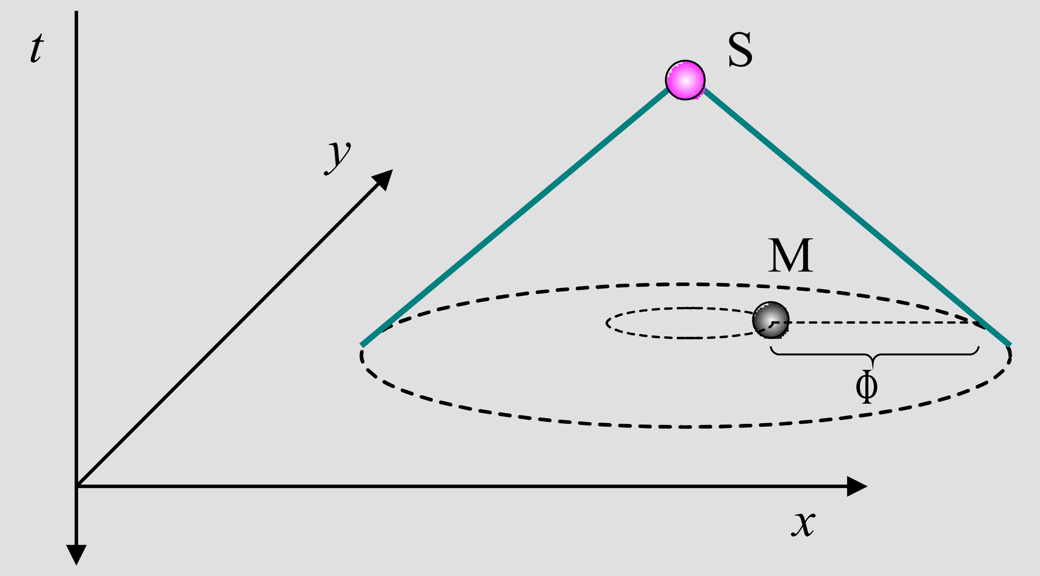

Figure 1: Iterative Cone Alignment method. Microphones are represented by particles on the surface of a cone in $p{+}1$-dimensional space.

- 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.

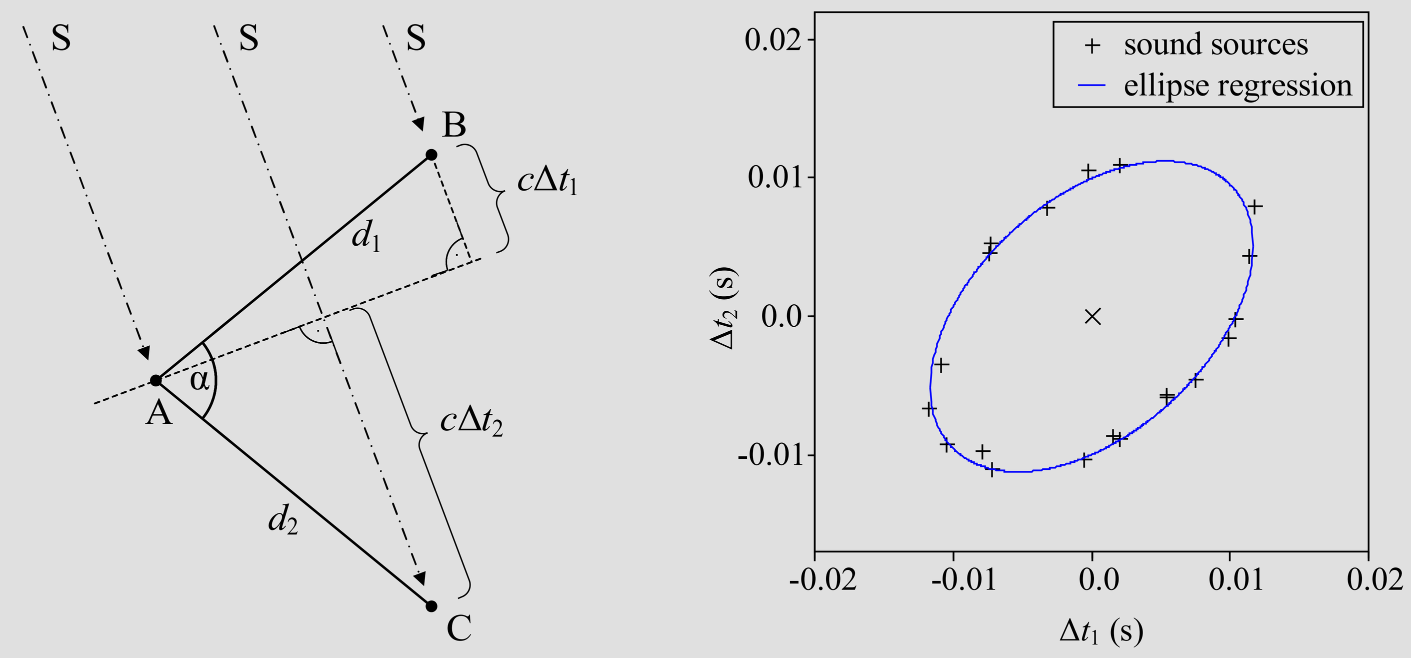

Figure 2: Ellipsoid TDOA method. *Left*: Three microphones A, B, C receive a distant signal S. *Right*: The time differences Δt_1 and Δt_2 form an ellipse which contains the distance information of d_1 and d_2.

Smartphone application

We have implemented our algorithms in an application for Windows laptops and for the Apple iPhone [2]. The devices are connected in a Wi-Fi network and they are synchronized. The built-in microphones of the devices record the environment. When sound signals are detected their points in time are exchanged among the connected devices.

Timestamp detection is done by threshold comparison: The moment when the audio signal rises above an environment noise dependent threshold is logged. Calculation results are displayed in an interactive OpenGL visualization.

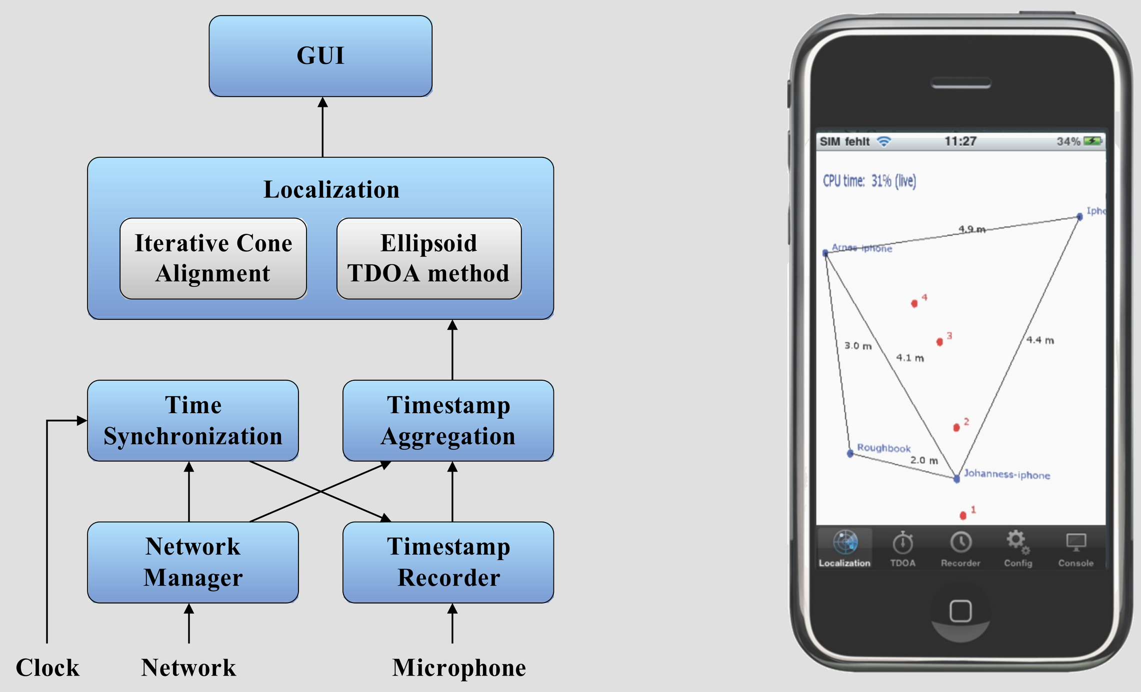

Figure 3: Software structure diagram and a screenshot of the software running on Apple iPhone.

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 × 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 (σ = 0.14 m) remained.

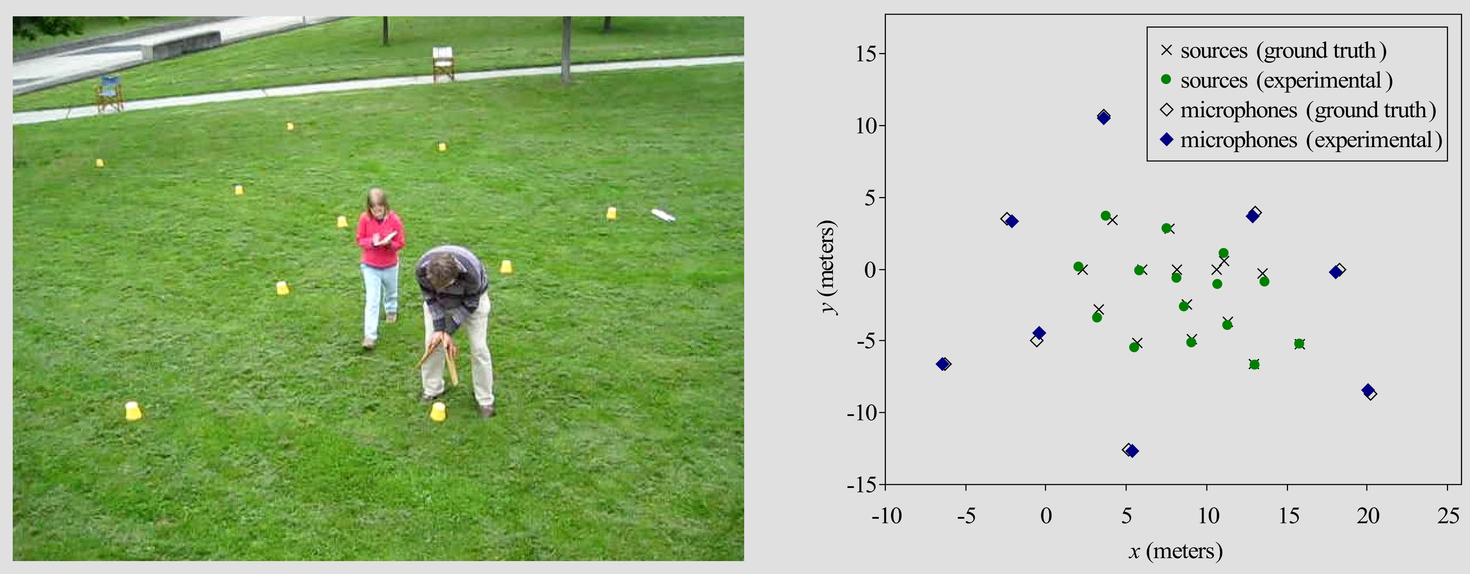

Figure 4: *Left*: The experimenter making a sound signal. *Right*: Positions of microphones and sound sources, compared to the ground-truth.

Acknowledgements

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References

[1] T. Janson, C. Schindelhauer, and J. Wendeberg. Self-Localization based on Ambient Signals. *ALGOSENSORS 2010*, to appear in LNCS, Springer, 2010.

[2] T. Janson, C. Schindelhauer, and J. Wendeberg. Self-Localization Application for iPhone using only Ambient Sound Signals, *2010 International Conference on Indoor Positioning and Indoor Navigation*, accepted, 2010.