Self-Localization Application for iPhone using only Ambient Sound Signals

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1 Introduction

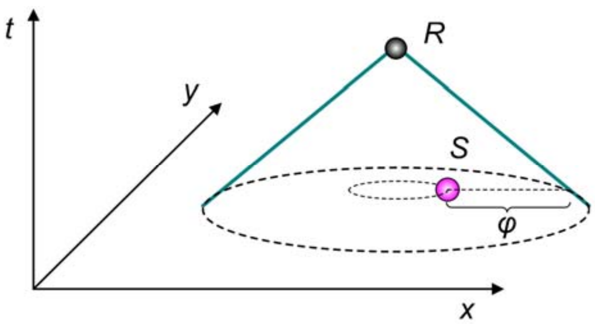
We present a smartphone application to localize a group of devices in a mobile environment without the need of any further infrastructure. Ambient sound signals are the only information source. Time marks are assigned to the recorded audio stream for each distinctive audio event. Then we evaluate the time differences of arrival (TDOA) between devices. The innovation of our approach is, that we need absolutely no positional anchor points in space – neither any predefined smartphone positions nor the positions of the environmental sounds. This stands in contrast to common multilateration approaches. However, we use a WiFi connection to establish a common timebase between the devices and to exchange time marks. In this way the employment in dynamic environments with random sound events is made possible, e.g. in crowded areas like market places or concerts, or for thunderstorm tracking. Especially, the application becomes useful when established positioning systems (e.g. GPS) are too imprecise or fail, as during underwater self-localization of scuba divers. In our experiments we evaluated the audio information and synchronized the devices up to an order of 0.1 ms. This led to a positioning precision in the order of 10 cm.

2 Related work

Localization of mobile devices with additional infrastructure has been a broad and intensive research topic. Popular applications include GSM localization [1, 2] and WiFi network fingerprinting [3]. For *known* sender or receiver position information TDOA localization can be addressed in closed form [4, 5, 6] or by an iterative approach [7]. Moses et al. use TDOA with additional angle information (direction of arrival, DOA) to locate both *unknown* sender and receiver positions [8]. This requires expensive microphone arrays or directed microphones. Our approach uses only TDOA information without any further infrastructure.

3 Methods

We developed two new methods to address the self-localization problem of both unknown signal senders and receivers [9]. The *Ellipsoid TDOA method* reconstructs the positions for exactly three devices in two-dimensional space for the assumption of infinitely distant sound sources. This can be written in closed form and solved rapidly. Experiments pointed out that the assumption of remote sound sources still holds if the distances of the sound sources are just greater than twice the distances between the devices. The *Iterative Cone Alignment* method generalizes to arbitrary device numbers and no



assumptions on the signal origins. It relies on an energy minimization approach implemented in a physical spring-mass simulation. Fundamental is the signal propagation equation

$$\varphi \; = \; c\,(t_{R,S} - t_S) - \| R - S \| \tag{1}$$

where c is the signal velocity, S and R denote the unknown positions of senders and receivers in two-dimensional space, t_S is the unknown signal time and $t_{R,S}$ is the given sound signal time mark. || • || denotes the euclidean distance. Equation (1) describes a cone in (2+1)-dimensional space. The energy minimization approach simulates physical particles S and R for each signal and receiver (microphone). It attempts to restore valid positions of S on the cone surfaces of R. Except for symmetries, for a sufficient number of senders and receivers this leads to a globally unique solution of S with respect to every receiver and – implicitly – correct distances between pairs of receivers.

4 iPhone App

We use the Apple iPhone 3GS as a platform that combines a fast ARM11 CPU with the intuitive multitouch interface making it a good choice for our interactive software. The application ("App") serves both as an experimental platform for the development of our algorithms and as a nice and easy-to-use gadget for the public domain. Both localization schemes are included in our application. The Ellipsoid TDOA method requires three connected iPhones forming a triangle; at least four iPhones are necessary for the iterative method to obtain a unique solution. The algorithms rely upon discrete "timestamps", i.e. the times when short, steep edged audio signals arrive at the devices. The signals are recorded via the built-in microphones and then analyzed by audio processing. Results of the calculations are displayed in an OpenGL visualization which can be rotated and zoomed using multitouch gestures.

5 References

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