Single Base-station 3D Positioning Method using Ultrasonic Reflections

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ABSTRACT

In context awareness applications the locations of people, devices or objects are often required. Ultrasound technology enables high resolution position measurements indoors. A disadvantage of state-of-the-art ultrasonic systems is that several base stations are required to estimate a 3D position. Since fewer base stations leads to lower cost and easier setup, a novel method is presented that requires just one base station. The method uses information from acoustic reflections in a room, and estimates 3D positions aided by an acoustic room-model. The method has been verified within an empty room. It can be concluded that ultrasonic reflection data contains valuable information on the 3D position of a device.

Keywords

Location awareness, location systems, ultrasonic positioning

1. INTRODUCTION

In future consumer electronics, context awareness will play an important role. Often, the locations of people, devices and objects are part of the required context information of which consumer devices need to be 'aware'. Within the PHENOM project [1], several application scenarios were developed that require in-home 3D device position information.

The required position accuracy (typically ≤ 1 m) can not be delivered by wide-area systems like GPS. Therefore, a specialized indoor positioning system is required. It may use radio waves (RF), magnetic fields, ultrasonic waves, or combinations thereof. We investigate systems based on ultrasonic waves, because of the potential high accuracy at low cost. State-of-the-art ultrasonic systems calculate distances from ultrasound time-of-flight measurements, and then use triangulation algorithms to calculate a 3D position. A disadvantage of this approach is that several units of infrastructure are required at fixed known positions in a room. Generally four base stations (BS) are required in a non-collinear setup to estimate 3D position. In special cases like ceiling-mounted BSs, three is sufficient. Fewer BSs would make positioning systems cheaper, and easier to set up. Therefore we investigate whether a positioning system can work with fewer BSs, or with just one BS (of small size) in the extreme case.

2. METHOD

A novel concept was developed [3] to realize a single-base-station 3D positioning system. It exploits reflections of ultrasonic waves against the walls, floor and ceiling of a room. How these reflections may help in position estimation will be explained in this section. A typical (processed) ultrasonic signal measured at some receiver in a box-shaped room is shown in Fig. 1. At time $t = 0$ a source emits a burst-like signal. Using time synchronization between devices (e.g. by an RF link such as in the Cricket system [4]) the receiver can measure the time-of-flight of ultrasonic signals, and then calculate the distance to the source. In the figure, the first peak at 2.89 m is the line-of-sight distance. The subsequent peaks are caused by reflections. These reflections were found to contain information about the position of the receiver. The information is contained within the pattern of amplitude peaks, called the *signature*, shown in the figure.

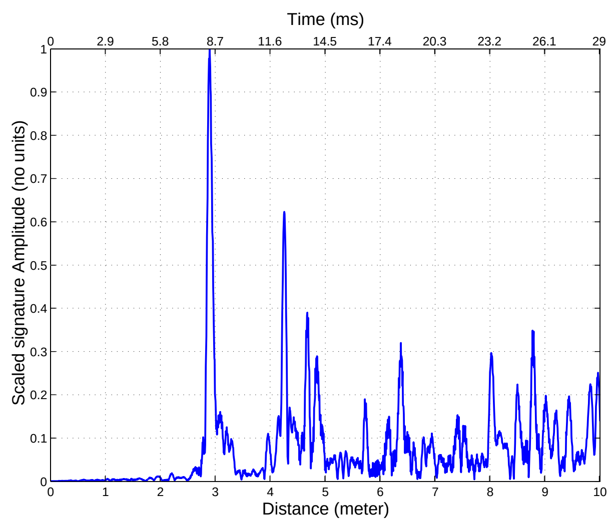

Figure 1: Measured signature at a receiver position. The horizontal axes show time (top) and corresponding distance interval $[0, 10]$ m.

Note that the fixed BS can be chosen to be either transmitting or receiving ultrasound. We chose it to be a transmitter, to allow many mobile device receivers to co-exist without causing ultrasonic interference problems between devices.

2.1 Acoustic model

To use reflections for positioning, a model was developed that relates 3D positions to reflection signatures. The fol-

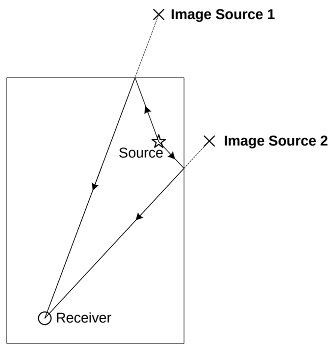

Figure 2: 2D top view of a room, containing one acoustic source and one receiver. Two acoustic reflections (arrows) and associated image sources (crosses) are shown.

lowing example will show the model's principle. Figure 2 shows a top view of a room with an ultrasound source. Two reflections of ultrasonic waves off walls are shown. These reflected waves can be considered as originating from two conceptual *image sources* marked by crosses. Many more image sources than those shown exist in a room, which can be calculated using the *image method* [2]. From here on we assume that the source shown is a BS at a fixed known position. It will give rise to many image sources, that can be seen as *virtual base stations* (VBS). We can think of VBSs as possible replacements for real BSs, thereby reducing the number of real BSs. To calculate the positions of VBSs, the room dimensions have to be known. The current room model includes 91 VBSs, and room dimensions are measured $\pm$ 5 cm accurate.

However, signatures are not only affected by position but also by device orientation. Therefore, source/receiver orientations and the directional beam pattern of ultrasound transducers are included in the acoustic model. The model furthermore includes the attenuation of ultrasound in air, resonance characteristics of piezo-electric ultrasound transducers, acoustic interference effects between reflection peaks (in case reflections arrive approximately at the same time), and wall reflection attenuation factors [3].

2.2 Signature matching method

Using the acoustic model, it is possible to calculate an expected acoustic signature given a 3D position and orientation. However, the reverse problem, of directly calculating 3D position and orientation given a measured signature, proves to be much harder. Therefore the former approach was used as our initial method for 3D position estimation, the *signature matching* method. It simply tries a set C of mobile device 3D candidate positions in the room, calculates an expected signature at these positions using the model, and compares those to the measured signature. Finally the best-matching candidate position is picked as the likely mobile device 3D position. Note that set C is a well-chosen subset of all possible room positions. Its size N_c ranged from 7243 to 11131 in our experiments, with a space between candidate positions of ≤ 5 cm. The current computational load for signature matching over set C is of the order $O(N_c \cdot 10^5)$ FLOPS, implying an update time of 1-10 s per measurement for an optimized implementation on a modern PC. This could be significantly improved by a smarter choice of C.

Since the acoustic model also needs a candidate *orientation* to calculate a signature, this orientation has either to be known in advance or estimated on-the-fly. Initially the former approach was used [3], but currently methods of orientation estimation are being developed.

3. RESULTS

A measurement setup was built to test the method. It consists of one piezo-electric ultrasound transmitter base station (BS) and one receiver, both connected to a measurement PC. All processing steps are implemented in software. Preliminary experiments have been performed in an empty office room, to verify the acoustic room model and to test the method in best-case conditions. The transmitter BS was fixed at a wall and the mobile receiver was placed at 20 different positions. A good position estimate was found in 18 positions, all with a positioning error of less than 20 cm. Two positions had higher errors of 0.77 m and 1.20 m. The errors were caused by a combination of three effects in the measured signature ('missing' peaks, 'noise' peaks, and random deviation of peak-amplitude from its expected value) that will be further investigated.

4. CONCLUSIONS AND FUTURE WORK

It can be concluded that measured ultrasonic signals contain useful information about the mobile device's 3D position. We propose to use this information to perform device position estimation, using a single base station per room. The *signature matching* method was developed for this purpose. Initial experiments show that the method works within an empty office room.

Future work is aimed at applying the method in realistic non-empty rooms. To realize this, several improvements to the basic method are being considered for increased robustness and calculation speed. One approach is a tracking system that integrates information from several measurements over time. Other approaches are based on small-sized transducer arrays, embedded in the base station.

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