Indoor Sound Based Localization
An inexpensive, easily deployable and widely compatible approach

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Abstract—This document states the key objectives of the proposed PhD work to be developed in the Doctoral Program in Electrical and Computer Engineering. It proposes the development of an inexpensive and widely compatible indoor sound based localization. Using sound will allow using low cost off-the-shelf equipment suitable for keeping a low deployment cost. Although the research work is in its first steps, the current document provides a wide view on the problem while discussing some possible approaches and predicting some possible problems to overcome.

Keywords-context-aware; sound based localization; TOA; TDOA; multilateration; trilateration;

I. INTRODUCTION

One of the most popular research areas in ubiquitous or pervasive computing is the development of location-aware systems. These are systems in which electronic devices provide the users some kind of information or service depending on their location. The basilar component of a location-aware system is the location-sensing mechanism. This PhD work has the goal to develop an inexpensive, easily deployable and widely compatible localization system appropriate for indoor use suitable for pre-installed public address sound systems, avoiding costly installations or significant architectural changes in spaces.

The most widely used location system in the world is the well-known GPS, satellite-based navigation system. However, GPS doesn’t work well below a roof or without direct line-of-sight to satellites. Indoor localization solutions have closer beacons (than satellites) and use radio signals, sound, ultrasound, infrared, video and others use a combination of them. Each one has their own strengths and may be very useful in their respective application domains. However these systems are not suitable for all applications and are typically prohibitively expensive for wide deployment: “Good applications are those that achieve an adequate equilibrium between system requirements, technological advantages, and associated costs” [1].

In the attempt to build such a localization system, audible sound as a way to measure distance is exploited. It’s not uncommon that indoor spaces have some kind of sound system with speakers uniformly distributed providing good sound coverage. There are many examples where how this sound localization approach could be used: train or subway stations, airports, large department stores, shopping plazas, amusement parks, museums, office buildings etc. The subway station example is actually the starting point of this research work, as previous work has been developed by the authors in the NAVMETRO project [2] that has shown the need to have some automatic solution to the localization problem in closed spaces. This previously developed setup will provide a solid testing platform and the concrete proof of validity of the developed work.

II. STATE OF THE ART IN LOCALIZATION

A review on the state of the art shows that the indoor Position Location (PL) problem was already address by many approaches with different technologies. There are infrared systems like the “Active Badge Location System” where a device produces periodic signals that will be received by a spatially wide network of sensors that localize the device’s signal [3]. Interference from florescent light and sunlight raise problems. Ultrasound technologies like the “Active Bats” [4] or the “Crickets” [5] are also used to localize a device. However they require ultrasound tags and ceiling-mounted ultrasound receivers to capture the tag’s signal. Both infrared and ultrasound approaches require special installations, sensors or devices. Due to the wide diffusion of Radio Frequency technologies, RSSI (Received Signal Strength Information) based localization techniques have been reported as a possible solution to low cost and easy to implement installations that allows tracking RF devices. As they use the RSSI to estimate distance, problems like wall attenuation, reflections, obstacles or significant changes in the electromagnetic environment, end up producing erratic positioning results that are not suitable for precise positioning. They are although still useful for some less demanding applications. One example on a Wi-Fi based solution is the Eakauhau location engine [6] that uses a pre-existing Wi-Fi installation where special tags or Wi-Fi clients are localized with RSSI information entered in a previously constructed model. Other example approaches are the RFID base localization systems [7] that even though robust, have very low position resolution as it relies in having as many locations as RFID separate fields. Artificial vision based systems are also a possibility, and stereovision systems are pointing some new directions [8], but they are expensive as require many cameras and heavy processing. Inertial Navigation Systems (INS) together with RFID are also being explored to tackle the PL problem. The smartphone “advent” and their use of Micro-electromecanical Systems (MEMS) allow integrating their information (i.e. acceleration) to get relative positioning. To overcome this usual “dead reckoning” problem [9], RFID techniques are used to calibrate position now and then. A very interesting example is found in [10].

Some sound-based techniques to infer on an object’s or device’s position are also found. Most of them use sound as a natural consequence of their operation, just like airplanes that produce noise that can be used to track airplanes [11]. Other possibilities rely on having microphone arrays [12] to track some sound source positioning by AOA (angle of arrival techniques). Another possible approach is sound fingerprinting based where a technique named “Acoustic Background Spectrum” is conducted to uniquely identify rooms or spaces in a passive way, just with the usual noise “fingerprint” of the space [13].
III. RESEARCH QUESTION

How to use sound to automatically localize a device indoors using a common sound installation without disturbing the acoustic environment? To successively accomplish answering this apparently simple question with complex issues, one may divide the problem into four possible sub questions:

A. How to localize a device?

This is probably the most common subject on the research work in this area. It relies on the established framework of localization no matter the technology or the application. From the simplest example of getting the \( x, y \) coordinates (in the 2D problem) of a certain position, until the use of techniques to infer the distance that goes from the loudspeaker to the receiver at the device’s position.

![Figure 1. Position as function of the distance from the sound sources](image)

Localization algorithms considering this audible sound approach require measurements of range with reference fixed landmarks. Ranging can be achieved using different signal measurements such as time of arrival (TOA) or time difference of arrival (TDOA). Using sound instead of radio frequency signals can provide better resolution and less numeric instability, since the speed of sound is very much smaller than the speed of light. Using time, knowing speed and considering some not least important environmental conditions one may infer distance considering sound propagation.

B. What kind of sound?

The choice of sound to be used to define the position of a certain device is one of the most important decisions. One of the most obvious problem constraints is the need to disguise the necessary stimuli in the “natural” environmental sound. This is the key issue in using audible sound. It accomplishes the low cost objective allowing the possibility of not requiring extra equipment in the installation other than the ordinary loudspeaker, but at the same time it poses some difficult challenges concerning sound pollution. Increasing noise may turn this position determination not desirable. That is the key challenge of using the audible sound spectrum. An approach exploring possibilities like using high frequencies (enough to pass the loudspeaker filter and still be captured by the device microphone), sound watermarking [14] or frequency or time masking [15], will be performed to choose the most promising way of successfully locate the device while not disturbing the acoustic environment.

C. Which device to use?

To explore the most convenient scenario regarding possible applications with persons and the stated low cost requirement, the possibility of using GSM cell-phones will be investigated. This would be convenient since almost all persons use one. However, many problems may arise specifically due to some technology and equipment limitations, starting on its microphone (the receiver transducer), its codec (to compress the audio’s digital signal) or simply the GSM delay from the distance to the antennas and operator. This possibility will be thoroughly explored. However, if imperative limitations are found, a suitable cheap hardware device will be designed and implemented.

D. Acoustic space

The propagation environment may cause signal shadowing and reflections that may introduce a multipath scenario in which reflected copies of a transient signal travel longer distances than the direct line of sight. Additive combinations of reflected signals cause field intensity variations or fading. These phenomena occur in acoustic environments, and their nature and characteristics are highly dependent on the operation frequency band, and even on temperature, for the case of acoustic signals. These errors may be reduced through signal processing techniques like filtering, averaging practices, and multiobservation or redundancy. These improvement practices are usually difficult to implement and will surely present an interesting challenge.

IV. CONCLUSIONS

The presented work is still on its first developments. It is of capital importance to understand the boundaries of the problems in hands to have a good problem formulation. A complete research plan may prevent following some not so productive directions.

REFERENCES

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