PANDAA: A Physical Arrangement Detection Technique for Networked Devices through Ambient-Sound Awareness

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ABSTRACT

This demo presents PANDAA, a zero-configuration automatic spatial localization technique for networked devices based on ambient sound sensing. We will demonstrate that after initial placement of the devices, ambient sounds, such as human speech, music, footsteps, finger snaps, hand claps, or coughs and sneezes, can be used to autonomously resolve the spatial relative arrangement of devices, such as mobile phones, using trigonometric bounds and successive approximation.

Categories and Subject Descriptors

C.3 [**Special-purpose and application-based systems**]: Signal processing systems.

General Terms

Algorithms, Design, Experimentation.

Keywords

Arrangement detection, networked devices, localization.

1. INTRODUCTION

Future ubiquitous home or office environments can contain 10s or 100s of consumer devices connected through wireless networks, such as mobile phones, laptops, smart TVs, printers, etc. Ubiquitous services running on these devices (i.e. localizing users, routing, security algorithms) will commonly require an accurate location of each device. PANDAA (Physical Arrangement Detection of Networked Devices through Ambient-Sound Awareness) is a spatial localization technique for networked devices in office and home environments. Different from previous work that uses special-purpose hardware (e.g. ultrasonic transmitters [2]) or intrusive audible chirp sound [3], PANDAA leverages ambient sound randomly and passively generated in indoor environments to automatically determine the physical arrangement of devices without prior calibration of their location. To the best of our knowledge, PANDAA is the first indoor arrangement detection technique that relies purely on the use of ambient sounds and achieves high accuracy.

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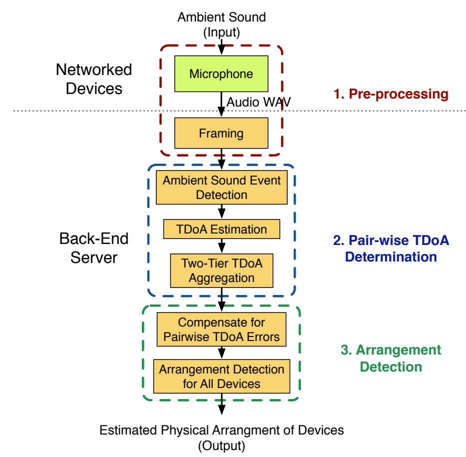

Figure 1: The system architecture of PANDAA.

In this demo, we will show how the system operates, how the algorithms in PANDAA manage to compensate for various ambient noises, and highlight the system's high accuracy of location estimation (about 0.17m precision in a 50m^2 indoor space).

2. THE PANDAA TECHNIQUE

PANDAA leverages microphones that already exist in various consumer devices, such as mobile phones, laptops, smart TVs, and context-aware systems (e.g. indoor acoustic sensing systems [1, 4]), to detect usable segments of ambient sound generated in a room. The time difference of sound arrival (TDoA) between devices is calculated and used to iteratively estimate inter-device distances. These distances are then used to determine the overall arrangement of devices. Finally, multiple TDoA measurements are combined to improve arrangement detection accuracy over time. The system architecture of PANDAA is shown in Figure 1.

The PANDAA system addresses several major challenges of ambient sound-based arrangement detection as follows.

Challenge 1: Choosing Usable Ambient Sound Segments. Ambient sounds, such as music played on a radio, human speech, noise from a working vacuum cleaner or a barking dog, may vary significantly in signal-to-noise ratio (SNR). Low SNR sound may lead to poor TDoA estimation accuracy. PANDAA addresses this challenge using an algo-

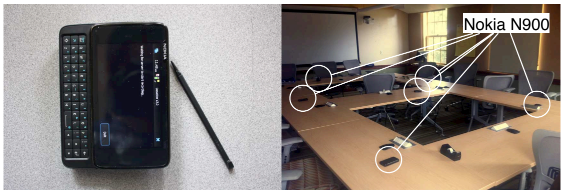

Figure 2: Left: A Nokia N900 phone that is used in the demo. Right: A meeting room where previous experiments were conducted.

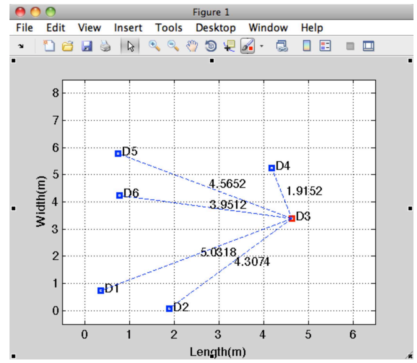

Figure 3: GUI that shows the estimated physical arrangement of devices (represented by blue squares) in the demo.

rithm that detects *impulsive sounds*. Impulsive sounds are short duration sounds with relatively higher amplitude, such as human cough, finger snaps, or beats in a song. Using this approach, PANDAA can automatically extract high SNR sound events from a variety of ambient sound types, and compute time difference of sound arrivals (TDoA) between devices.

Challenge 2: Correcting Inaccurate TDoA Measurements. In indoor environments, TDoA measurements can be affected by environmental factors, such as reflections, non-line-of-sight path, or ambient noise. To compensate for TDoA errors, PANDAA uses a novel two-tier TDoA aggregation algorithm. The lower tier aggregates cross-spectrums over successive audio frames in the same sound event to suppress any uncorrelated frame-to-frame effects. To handle longer lasting ambient effects, such as a moving person blocking acoustic line-of-sight of several nodes, the upper-tier aggregation averages TDoA estimates over multiple consecutive sound events belonging to the same sound source.

Challenge 3: Localizing Devices From TDoA Measurements. TDoA measurements from one single sound source are insufficient for estimating distance between two devices. PANDAA addresses this challenge by considering TDoA measurements from multiple ambient sound sources over time, to obtain pairwise TDoA measurements as an estimate of the lower bounds of the inter-device distances, and use the distribution of TDoA measurements to estimate the true inter-device distances, from which device arrangement is derived.

3. IMPLEMENTATION

We have implemented the PANDAA system on Nokia N900 mobile phones. The software on the phones was written in C++, including the sound event detection, the device synchronization, and the audio transmission modules. The code on the server was written in MATLAB, including the TDoA aggregation and the location estimation module, as well as a graphical user interface (GUI) for displaying the actual and estimated device arrangement. Figure 2 (left) shows a Nokia N900 phone displaying client-end GUI during an experiment. Figure 2 (right) shows a typical meeting room where we did our previous experiments.

The mobile phones are synchronized between each other using well developed synchronization techniques. To achieve required precision, we used the Network Time Protocol (NTP) to synchronize the devices to a laptop and modified the standard QT libraries to timestamp the audio recording with high precision.

4. DEMO DESCRIPTION

We will demonstrate the PANDAA technique that comprises a number of mobile devices connected through wireless networks. Several mobile phones and laptops will be randomly placed in the demo area, without calibrating their locations. Then, attendees will be encouraged to generate a number of ambient sounds at different and arbitrary locations in the demo area, such as human speech, coughs, finger snaps, hand claps or by singing a song. We will then use our laptop that runs the server-end program to show the detected impulsive sound segments (events) in real time, as well as the estimated device arrangement on a GUI. Figure 3 shows the GUI that will be used in the demo. As ambient sounds are generated in the demonstration area, the estimated device arrangement will be updated in real time.

We also develop software packages of PANDAA's client-end code, and provide the packages in terms of Android apps or iPhone apps on the Web. Attendees will also be encouraged to download these apps to their own mobile devices, and use the PANDAA technique to localize their devices during the demo.

5. REFERENCES

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