Unsynchronized Acoustic Indoor Positioning

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In collaboration with
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Overview

Introduction
System
Algorithm
Implementation
Video
Positioning Process
Conclusion and Demo
Motivation

• There is great interest in Indoor Positioning
• Real life examples:
  ▪ Where is the cheese aisle?
  ▪ Where is my flight gate?
Motivation (Cont.)

• We would like to help you find your way

• Use your own smartphone

• Simple
Why Acoustics?

• Why not WiFi or Bluetooth?
  ▪ Lower cost
  ▪ Access to raw data

• Acoustic waves propagate slower
  ▪ Higher Resolution
Background
Background

- Most solutions are synchronized  [Peng et al. ‘12]
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• Non-Synchronized ➔ High user demands [Ureña et al. ‘07]
Background

- Most solutions are synchronized. [Peng et al. ‘12]
- Non-Synchronized ➔ High user demands. [Ureña et al. ‘07]
- Current systems experience problems.
Project Goals

- Acoustic Indoor Positioning System
- Self calibrating and no synchronization required
- Cost effective → User’s smartphone
- Multiple users
- Simple Real-Time solution

Introduction
System

Algorithm

Hardware

Software
System

- **Algorithm**
  - Signal correlation
  - Distance calculation
  - Location estimation
System

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- Hardware
  - Android phones
  - Loudspeakers
System

- **Algorithm**
  - Signal correlation
  - Distance calculation
  - Location estimation

- **Hardware**
  - Android phones
  - Loudspeakers

- **Software**
  - Central server
  - Client application
System Configuration

Unsynchronized Beacon

Cloud Server

Unsynchronized Beacon

Unsynchronized Beacon

Unsynchronized Beacon
System Configuration (Cont.)

Cloud Server

Unsynchronized Beacon

Unsynchronized Beacon

Unsynchronized Beacon

Unsynchronized Beacon
Project Starting Point

- Android application
  - Limited to two phones
  - Phones are active devices
- Server – Only controls communication

[Peng et al. ‘12]
Algorithm Overview
Algorithm Overview

- Active Distances
- Area Spanning
- Passive Positioning

Distance
Algorithm Overview

Active Distances

Area Spanning

Passive Positioning
Algorithm Overview

- Active Distances
- Area Spanning
- Passive Positioning
Distance Between Two Beacons

- Round trip and response times are measured
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- Round trip and response times are measured

**Diagram:**
- Device 1 and Device 2 start recording
- Device 1 receives own signal
- Device 2 receives own signal
- Device 2 receives Device 1 signal
- Device 1 receives Device 2 signal
- $\Delta T$, $\Delta t$
Distance Between Two Beacons (Cont.)

- Distance is calculated using the equation:

\[ d = \frac{\Delta T - \Delta t}{2} \cdot v_{\text{sound}} \]
Position Three Beacons

• Determine 1\textsuperscript{st} device on axis origin

![Diagram showing Device 1 on the axis origin](image)
Position Three Beacons

• Determine 1\textsuperscript{st} device on axis origin
• Determine 2\textsuperscript{nd} device on X-axis

\[ \text{dist}(d_1, d_2) \]

Device 1 \hspace{2cm} Device 2
Position Three Beacons

• Determine 1\textsuperscript{st} device on axis origin
• Determine 2\textsuperscript{nd} device on X-axis
• Set 3\textsuperscript{rd} device on upper circle intersection
User Positioning

- $\alpha$, $\beta$, $\gamma$ can be calculated
- We built an equation set to calculate $a$, $b$, $c$
User Positioning

- $\alpha$, $\beta$, $\gamma$ can be calculated
- We built an equation set to calculate $a$, $b$, $c$
- Results in underdetermined equation set

$$
\begin{pmatrix}
-1 & 0 & 1 \\
-1 & 1 & 0 \\
0 & 1 & -1
\end{pmatrix}
\begin{pmatrix}
b \\
c \\
a
\end{pmatrix} =
\begin{pmatrix}
d1 \\
d2 \\
d3
\end{pmatrix} -
\begin{pmatrix}
\beta \\
\gamma \\
\alpha
\end{pmatrix}
$$
User Positioning

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\begin{pmatrix}
\beta \\
\gamma \\
\alpha
\end{pmatrix}
\]
User Positioning (Cont.)

- The equation set has one degree of freedom
- Iterative solution:

Choose a → Solve for b, c → Calculate circle intersection → Iterate
User Positioning (Cont.)

- Search space determined by scene distances
Hardware

Laptop/Cloud – Server app

Smartphones – Recording, GUI

Loudspeakers – Signal emission

Router – Local network

Implementation
Software
Software

• Server –
  ▪ Controls the data flow
  ▪ Controls measurement process
Software

- Server –
  - Controls the data flow
  - Controls measurement process

- Signal processing
  - Online audio processing
Software

- **Server** –
  - Controls the data flow
  - Controls measurement process

- **Signal processing**
  - Online audio processing

- **Client** –
  - User interface
  - Beacon mode – Active transceiver
  - User mode – Passive receiver
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Video
Video
Positioning Process

Cloud Server

Unsynchronized Beacon

Unsynchronized Beacon

Unsynchronized Beacon

Client/Server request
Data transfer
Acoustic signal
Positioning Process

User requests measurement

Cloud Server

Unsynchronized Beacon

Unsynchronized Beacon

Unsynchronized Beacon

Unsynchronized Beacon

Positioning Process

Client/Server request
Data transfer
Acoustic signal
Positioning Process

- Cloud Server
- Unsynchronized Beacon
- Client/Server request
- Data transfer
- Acoustic signal
Positioning Process

Server requests to record

Unsynchronized Beacon

Cloud Server

Start recording

Unsynchronized Beacon

Start recording

Unsynchronized Beacon

Start recording

Unsynchronized Beacon

Client/Server request
Data transfer
Acoustic signal
Positioning Process

Cloud Server

Unsynchronized Beacon

Unsynchronized Beacon

Unsynchronized Beacon

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Server requests to emit signal

Unsynchronized Beacon

Client/Server request
Data transfer
Acoustic signal
Positioning Process

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Client/Server request
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Positioning Process

Unsynchronized Beacon

Unsynchronized Beacon

Unsynchronized Beacon

Beacon emits signal

Cloud Server

Client/Server request
Data transfer
Acoustic signal

Positioning Process
Positioning Process

Cloud Server

Unsynchronized Beacon

Client/Server request
Data transfer
Acoustic signal
Positioning Process
Positioning Process

Client/Server request
Data transfer
Acoustic signal

Finished emission

Beacon notifies completion

Repeat process for all beacons
Positioning Process
Positioning Process

Cloud Server

Unsynchronized Beacon

Server requests to stop recording

Stop recording

Client/Server request
Data transfer
Acoustic signal

Positioning Process
Positioning Process

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Clients upload recordings

Recorded data

Recorded data

Recorded data

Unsynchronized Beacon

Recorded data

Client/Server request
Data transfer
Acoustic signal
Positioning Process

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Positioning Process
Positioning Process

- Cloud Server
- Unsyncronized Beacon
- Signal processing
- Client/Server request
- Data transfer
- Acoustic signal
Positioning Process
Positioning Process

Client/Server request
Data transfer
Acoustic signal

Server sends results
User Interface

Positioning Process
User Interface

Positioning Process
User Interface

Passive Beacons

Passive Device

Positioning Process
Performance

• Computation time:
  ▪ Signal emitting 3x1 sec
  ▪ Signal processing

• Measurement accuracy 2-5% of region

Error: ~2%, 6 [cm]
ICASSP 2018
ICASSP 2018 Demos

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Conclusion
Achievements

- Indoor Positioning System
- No synchronization
- Scalability
- Low cost
- Multiple users
- Accuracy
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Indoor Positioning System

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Multiple users

Accuracy

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$r=1.31$ position found error=0.09
Future Work

• Shorten positioning times
  ▪ Analytical passive localization
  ▪ Signal shortening

• Signal optimization

• Distributed system

• Multiroom support

Conclusion
Thanks!
Thanks!

And now for the demo