EchoTag: Accurate Infrastructure-Free Indoor Location Tagging with Smartphones

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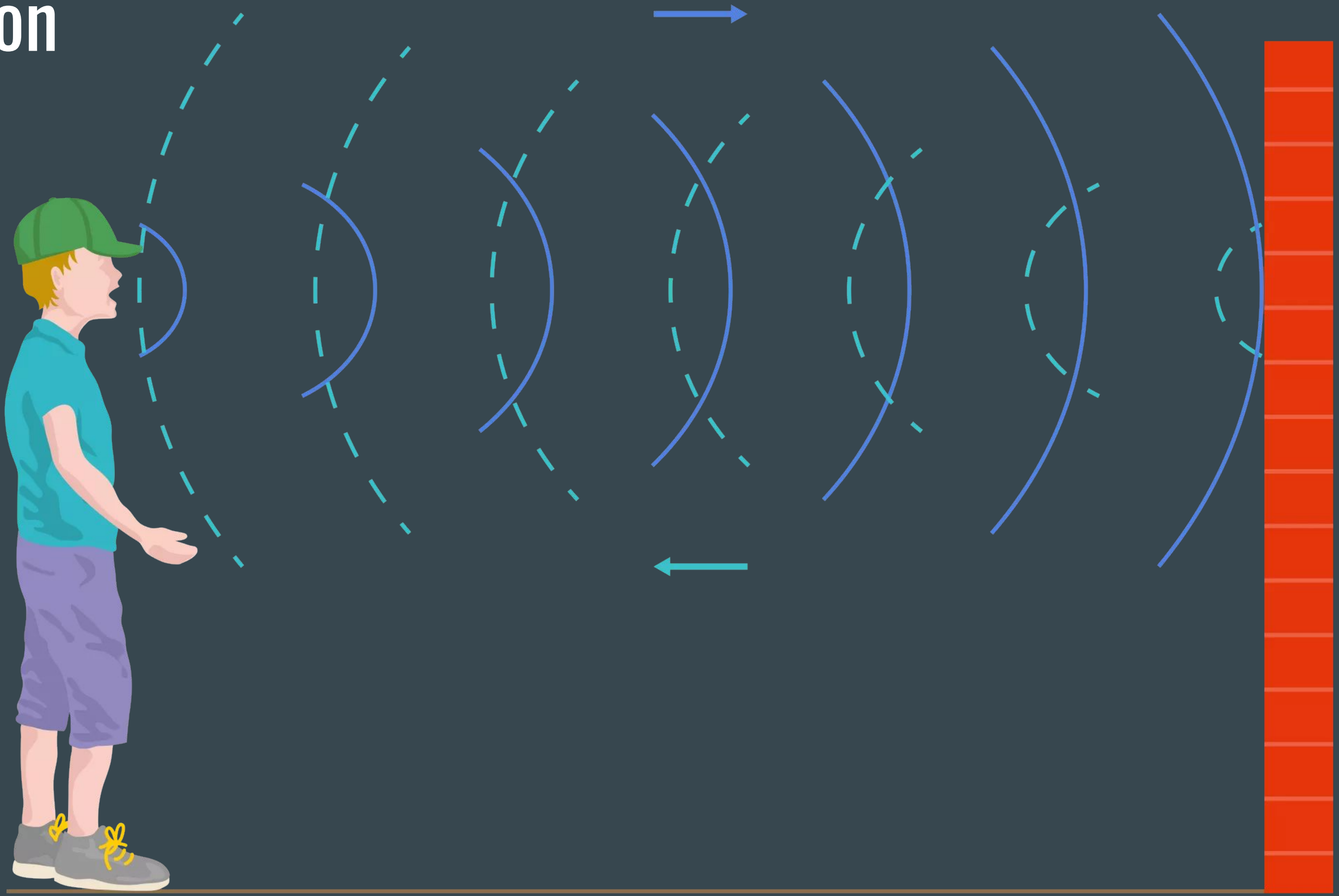
Intuition



EchoTag

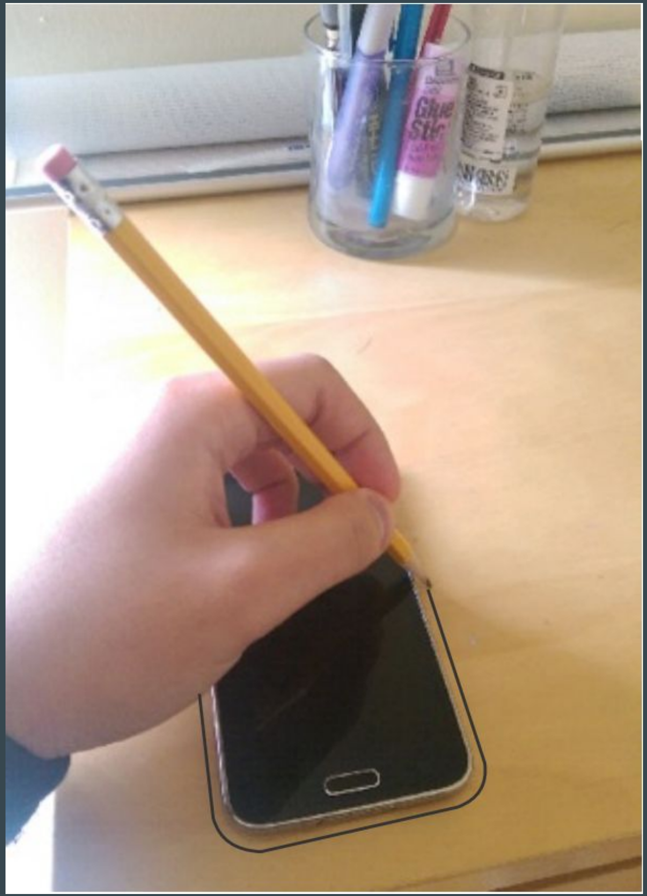
- Uses this intuition to implement indoor location "tagging"
- A tag is a location and associated actions
  - Phone could go to silent in class
  - Phone could automatically set an alarm in the bedroom

- Tags are created when user places phone at specific location
  - Phone "learns" location by emitting an audio signal

- Phones "remember" where they are based on received audio
  - ... and perform pre-defined actions

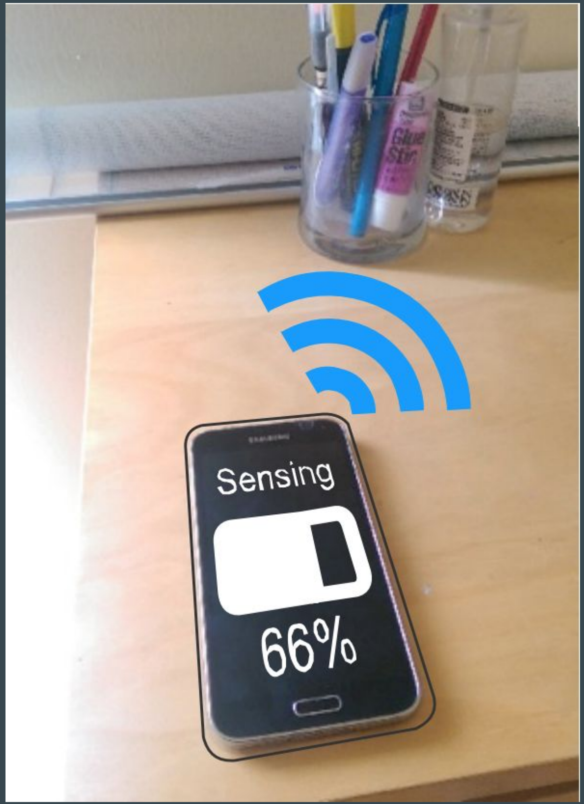
Using EchoTag - Drawing tags

- Help users remember tag location
- Can draw on paper and tape on surfaces



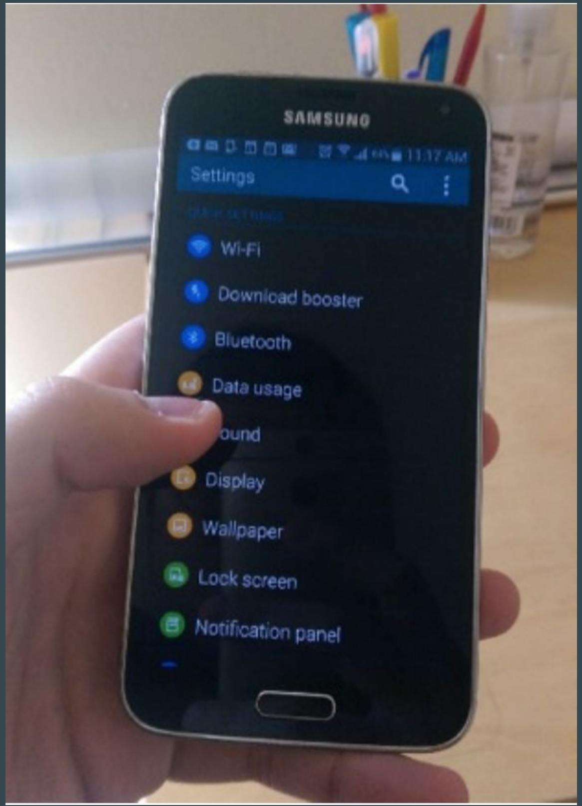
Using EchoTag - Sense acoustic signatures

- Use phone’s speaker to play a sound
- Use phone’s microphone to record echo



Using EchoTag - Select mapped applications

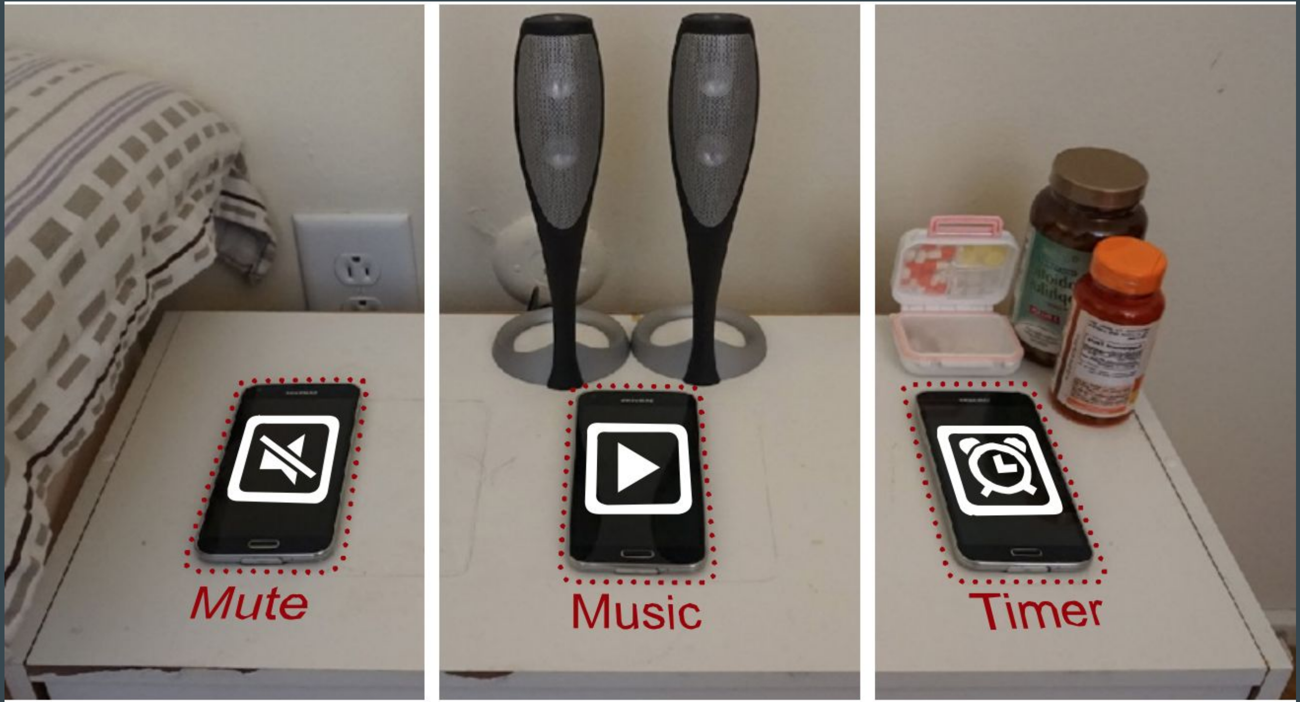
- Users specify and associate different actions with different tagged locations



Using EchoTag - Replay recorded tags

- Put phone back to tagged location to replay actions specified by users

EchoTag: Use cases



(a) Auto silent mode (b) Auto music (c) Auto timer

(How well) does it work?

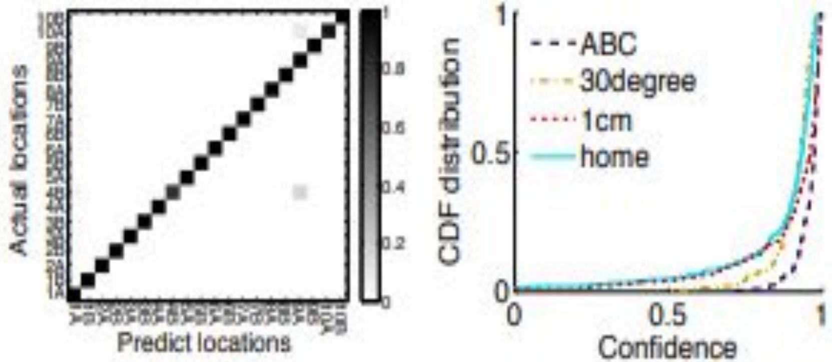
- In a “perfect” environment
  - Can distinguish 11 tags at 1cm resolution with 98% accuracy
  - Maintains 90% accuracy over a week

- Introducing foreign objects to room
  - Reduces accuracy to 56%

(How well) does it work?

(a) ABC tags (b) 1cm tags (c) 30° tags

Figure 12—Tag systems. The first tag system consists of disjoint (echo) tags while the second and third tag systems are composed of overlapped tags 1cm or 30° apart.



(a) Confusion matrix in home (b) Confidence distributions

Figure 13—Result of 30min dataset. *Confidence* is defined as the prediction probability at the target location minus the largest prediction probability at the other locations.

Implementing EchoTag

- Create an acoustic signature that is unique to a location
  - Must be robust to “spacial” and temporal changes
- Classification based on signature
  - Uses generic classifiers
- Usability
  - Is EchoTag useful? Obtrusive?

Acoustic Signature

- (Ideally) unique sound features that can identify location
- Training phase; phone emits a signal, records received echo.
- Features extracted from echo, mapped into large dimensional space for classification
- EchoTag uses Frequency Domain signatures (11-22Khz)
    - Depends on differing absorption across frequencies
- Acoustic signature augmented with wifi AP visibility and tilt sensor

Acoustic Signature

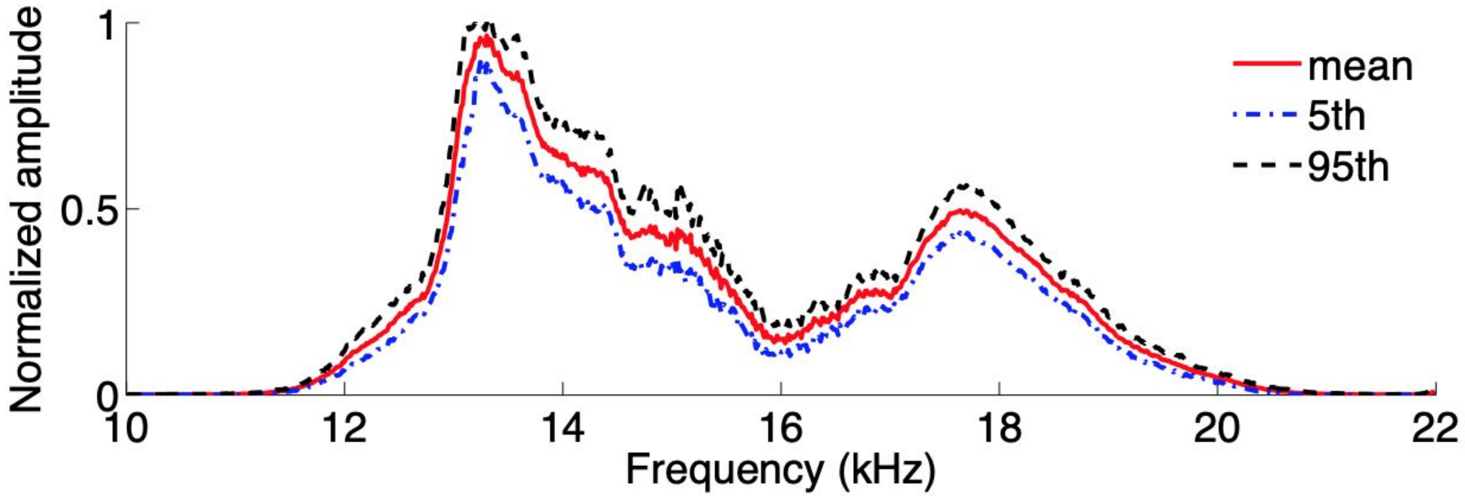


Figure 4—An example of acoustic signatures. The received attenuation of a flat frequency sweep is uneven over different frequencies. The result is an average of 100 trials over 1 minute.

Uneven Attenuation

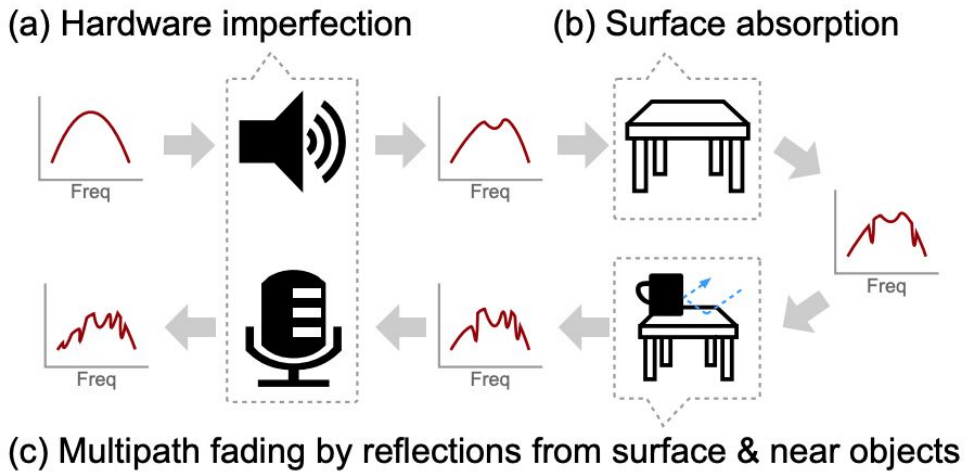


Figure 6—Causes of uneven attenuation. During the recording of emitted sound, hardware imperfection of microphones/speakers, absorption of touched surface materials and multipath reflections from nearby objects incur different degradations at different frequencies. Only the degradation caused by multipath reflections is a valid signature for sensing locations even in the same surface.

Acoustic signature generation

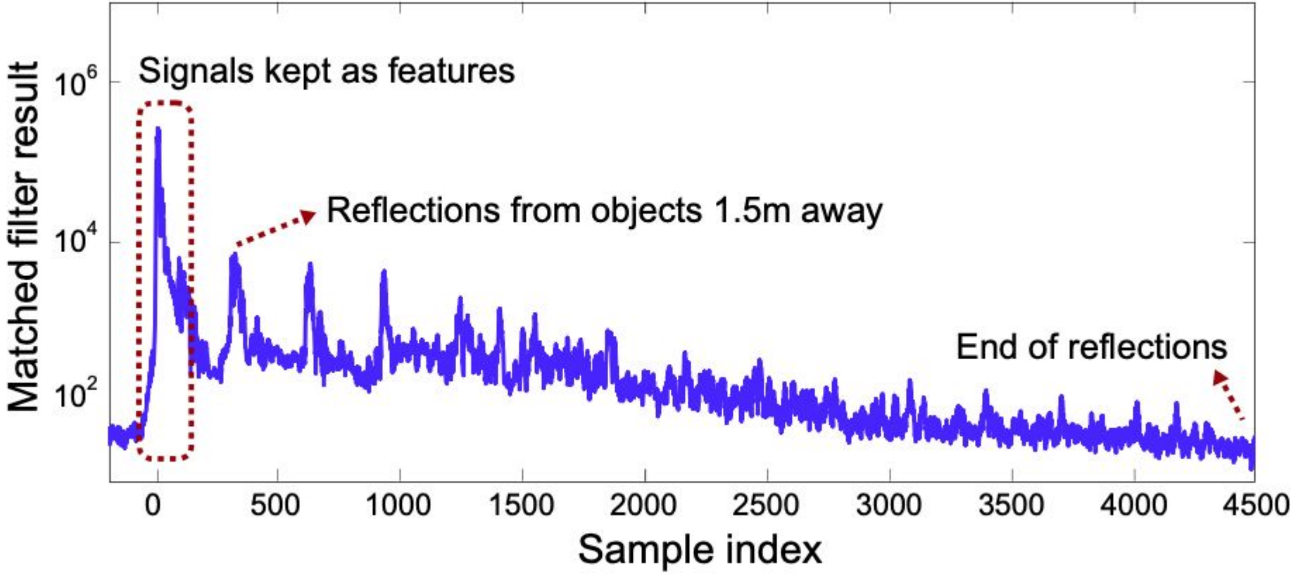


Figure 7—Characteristics of reflections. A matched filter is used to identify the reflections of a 100-sample chirp. Only first 200 samples after the largest peak are kept as a feature in `EchoTag`, excluding reflections from objects farther than 86cm away.

Classification

- Uses off-the-shelf classifiers
- Paper discusses K Nearest Neighbor (kNN) and Support Vector Machine (SVM)
- 200 features (samples after the first peak)

kNN

- 5 nearest neighbor using Euclidean distance
- 65% accurate over 1 cm resolution
    - Small training data, and non-linear acoustic signals

SVM

- One-against-all SVM
- N classifiers trained for N tags
- Location classified as tag #k if the kth classifier provides highest probability
    - Probability <50% means no tag is active

- Provides 98% accuracy over 1cm resolution

Optimization

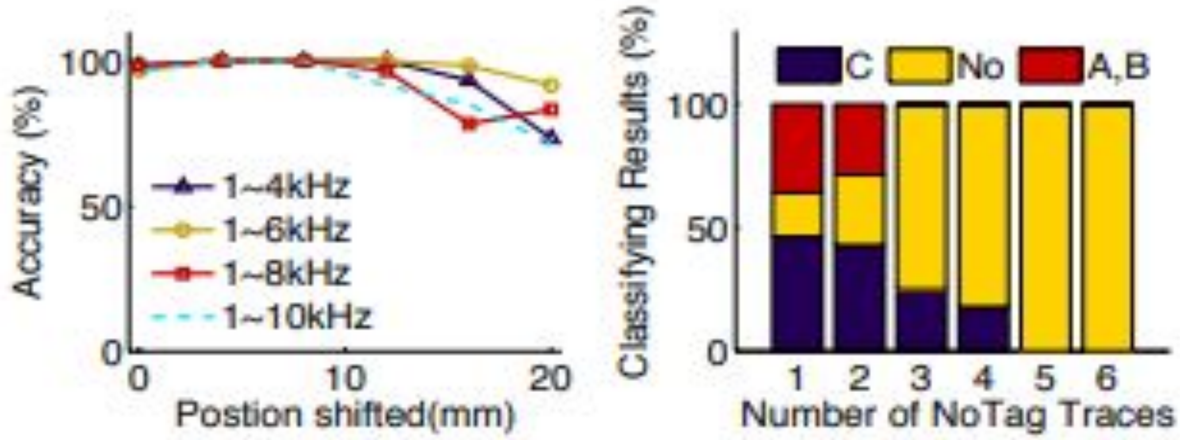
- Continuous audio sensing is expensive in terms of power
- EchoTag generates audio, which is obtrusive

- EchoTag is activated only if inertial sensor detects no motion
- Locations coarsely classified using WiFI AP ids
    - EchoTag not activated if known APs are not detected

Tolerance Range

- Can decrease sensing frequency in order to increase tolerance
  - This allows for it to be less accurate, which could be useful
- Also, implementing a “No Tag SVM” instead of trying to locate a tag
  - In there test had only 1% false negatives

Optimization



(a) Tolerance in lower frequency (b) NoTag SVM classifiers

Figure 21—Extension of tolerance range. The tolerance range can be extended by sensing tags with lower-frequency signals. Building 'NoTag' classifiers can also prevent `EchoTag` from incorrect classification of misplacements.

Usability

Questions	Disagree	No option	Agree
Sensing accuracy is useful	1	0	31
Sensing noise is acceptable	0	3	29
Sensing delay is acceptable	1	6	25
Placing phones inside (echo)tags is easy	0	3	29
`EchoTag` can help me remember turning on silent mode when going to sleep	2	5	25
`EchoTag` can help me remember setting the timer for taking washed clothes	5	3	24
`EchoTag` can save my time in activating apps under specific scenarios	1	0	31

Summary

- EchoTag uses acoustic sensing for indoor localization
- Actions associated with locations

- Acoustic signature based on frequency absorption

- 98% accuracy, 1cm resolution using all-against-one SVM
- Not particularly robust to environment

- User study to gauge utility

Related Work

System	Resolution	Infrastructure	Signature
SurroundSense [3]	room-level	No	Fusion
Batphone [25]	room-level	No	Sound
RoomSense [23]	300cm	No	Sound
Radar [4]	400cm	Existing	WiFi
Horus [30]	200cm	Existing	WiFi
Geo [8]	100cm	No	Geomagnetism
FM [7]	30cm	Existing	FM
Luxapose [15]	10cm	Additional	Light
Cricket [22]	10cm	Additional	Sound/WiFi
Guoguo [17]	6–25cm	Additional	Sound
EchoTag	**1cm**	**No**	**Sound**

Table 1—Existing indoor location sensing systems.