UbiTap: Leveraging Acoustic Dispersion for Ubiquitous Touch Interface on Solid Surfaces

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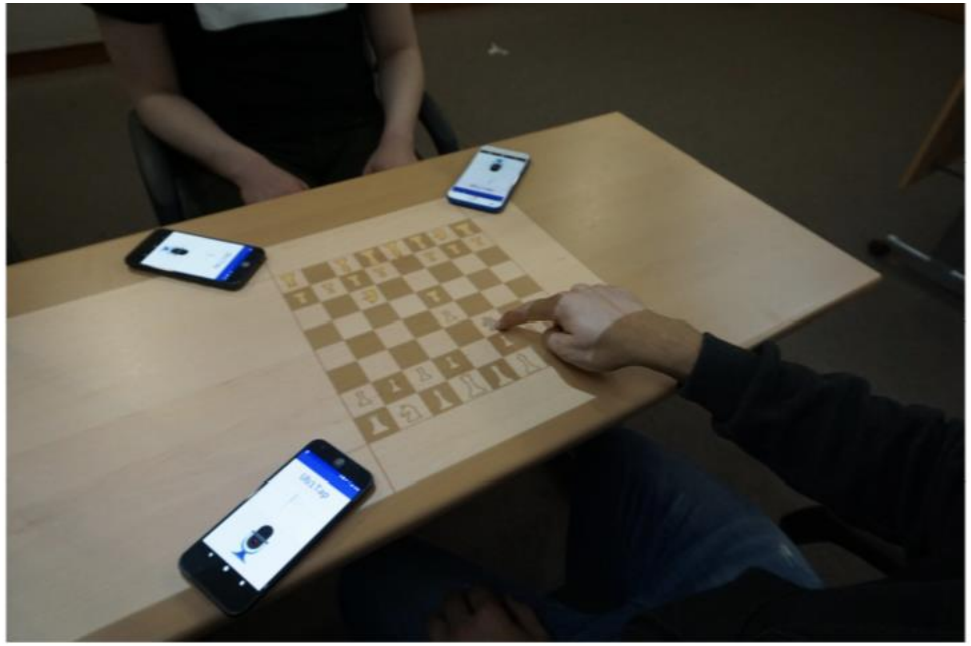
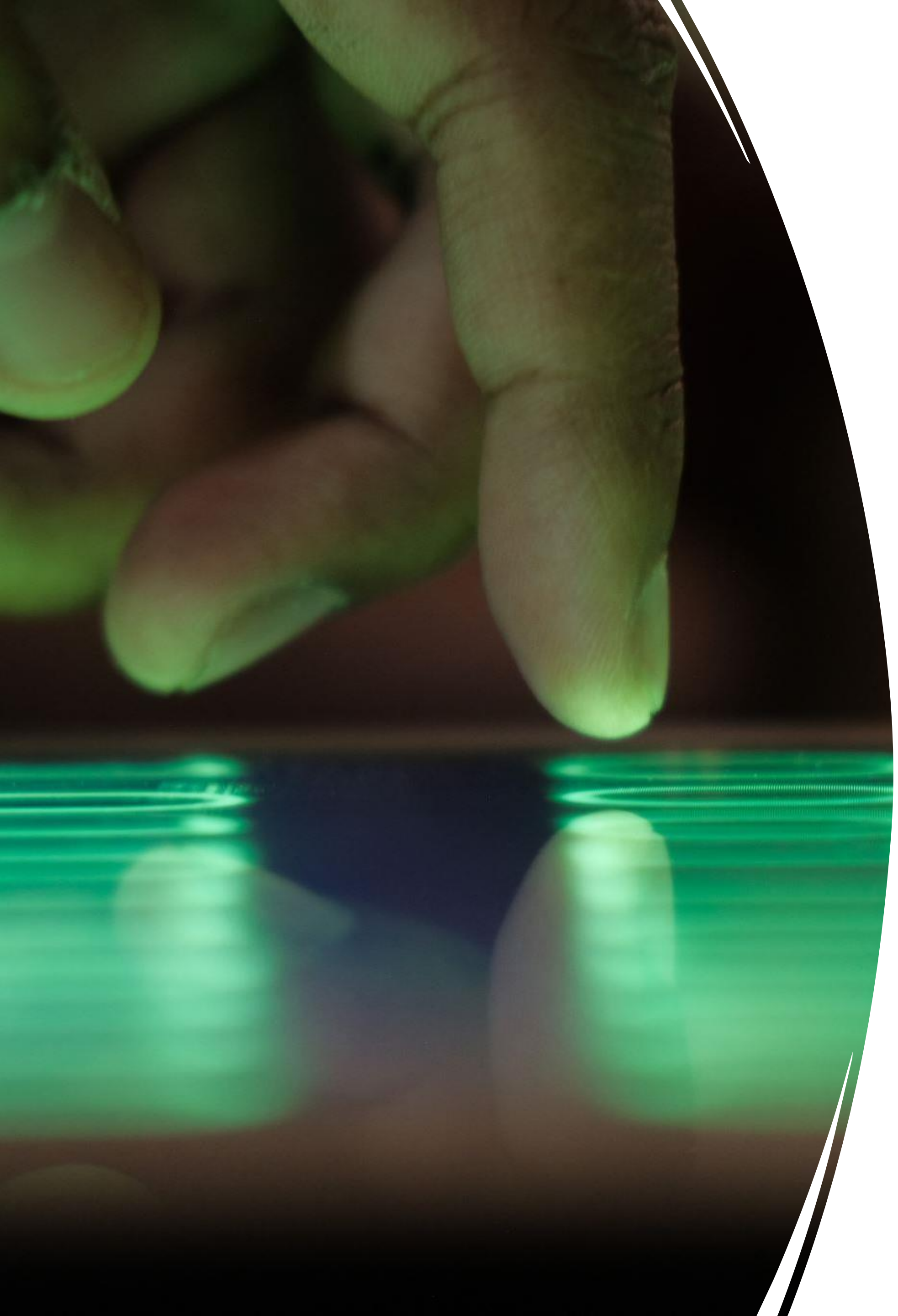
Ubitap

- Use a touch screen regardless of time and place, for example, board games



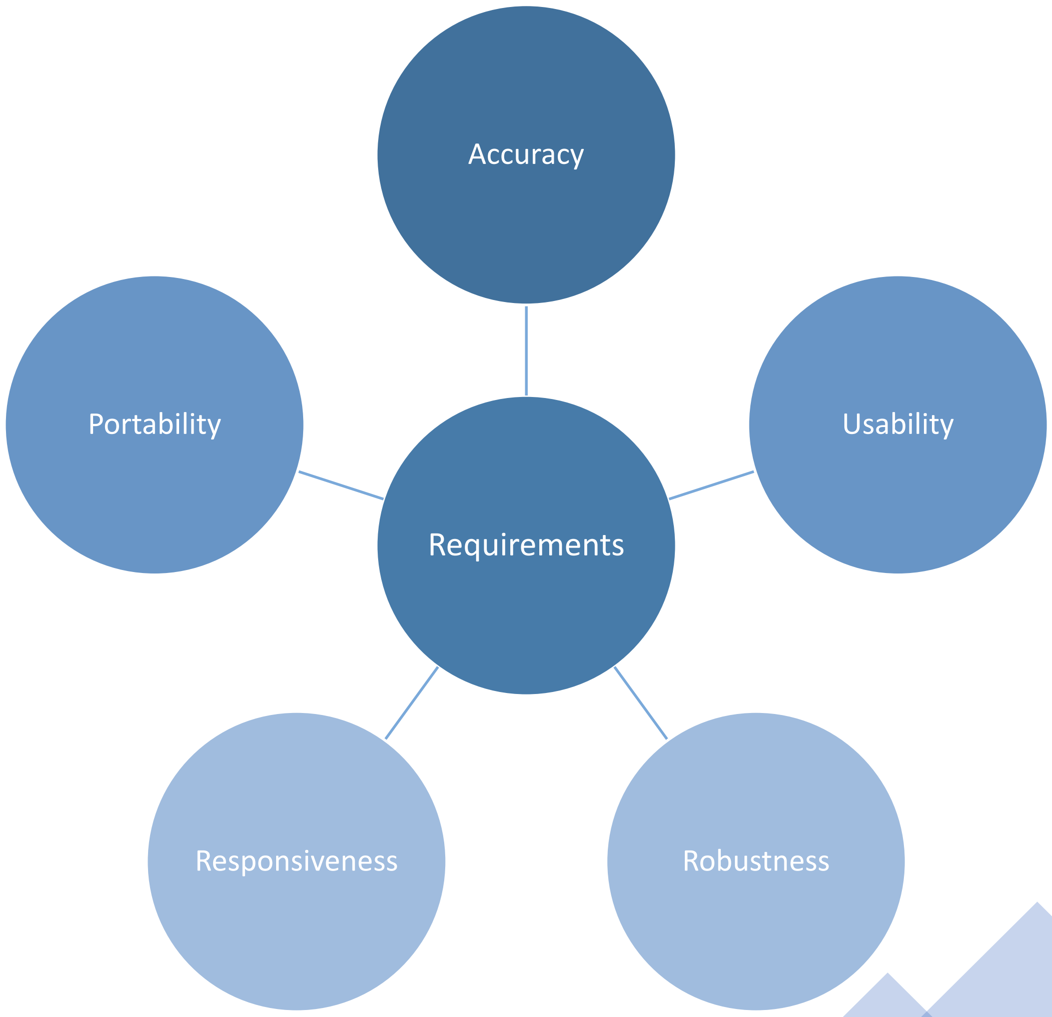
- Using touch screens with minimal resources, cutting down on cost and using built-in microphones in regularly used devices.



Ubitap

- Most recent trend! – seamless interaction with various devices using surfaces on objects as touch surfaces.
- Many previous works that have focused on tracking user’s fingertip on the surface
- Ubitap is an approach that takes on surface touch inputs in a unique way: by listening to the sound, without the loss of portability.
- It first records the sound using atleast 3 microphones (in-built). It then analyzes the wave and estimates the location of the sound.

Requirements of Ubitap



Challenges

- Variation in surfaces: Touchsound travels with different speeds on different surfaces. Users may use different surfaces depending on the environment.
- Relocation of touch input space: possibility to recreate the input for touchsound on a different area of the same surface.
- Changes in the surrounding environment: users may place new objects or displace already present objects which may affect reflection patterns

What’s lacking in current systems?

- Low usability and robustness
  - Prior works have utilized classification-based techniques
  - Accuracy > usability
  - Classifications may not be reliable as touchsounds may change depending on the environment.
- Low accuracy and portability
  - Prior works have utilized TDoA between microphones.
  - But accurate measurement of TDoA requires precise hardware with microphones, geophones, accelerometers
  - Lower accuracy due to dispersion

Acoustic Dispersion

- A touchsound causes the air pressure around it to change.
- Solid surfaces traverses different sound waves (of varying frequencies) at different speeds.
- Acoustic dispersion: the idea that different frequency components of the touchsound pass the area near microphones at different times.
- Speed of sound on solid surfaces > Speed of sound in air.

Key Principles

1. Different frequency components of a touchsound propagate at different speeds V(f), where f is their carrying frequency.

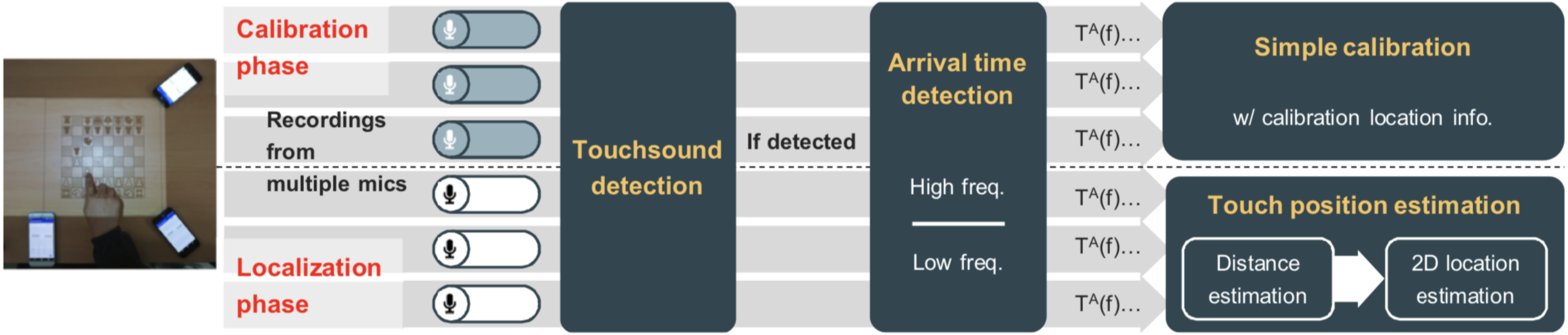
2. For a certain surface, V (f) is constant regardless of the touch location and the surrounding environment.

3. The TDoA between two different frequency components of a touchsound is linearly proportional to the propagation distance of the touchsound to a microphone (denoted as D), as follows:

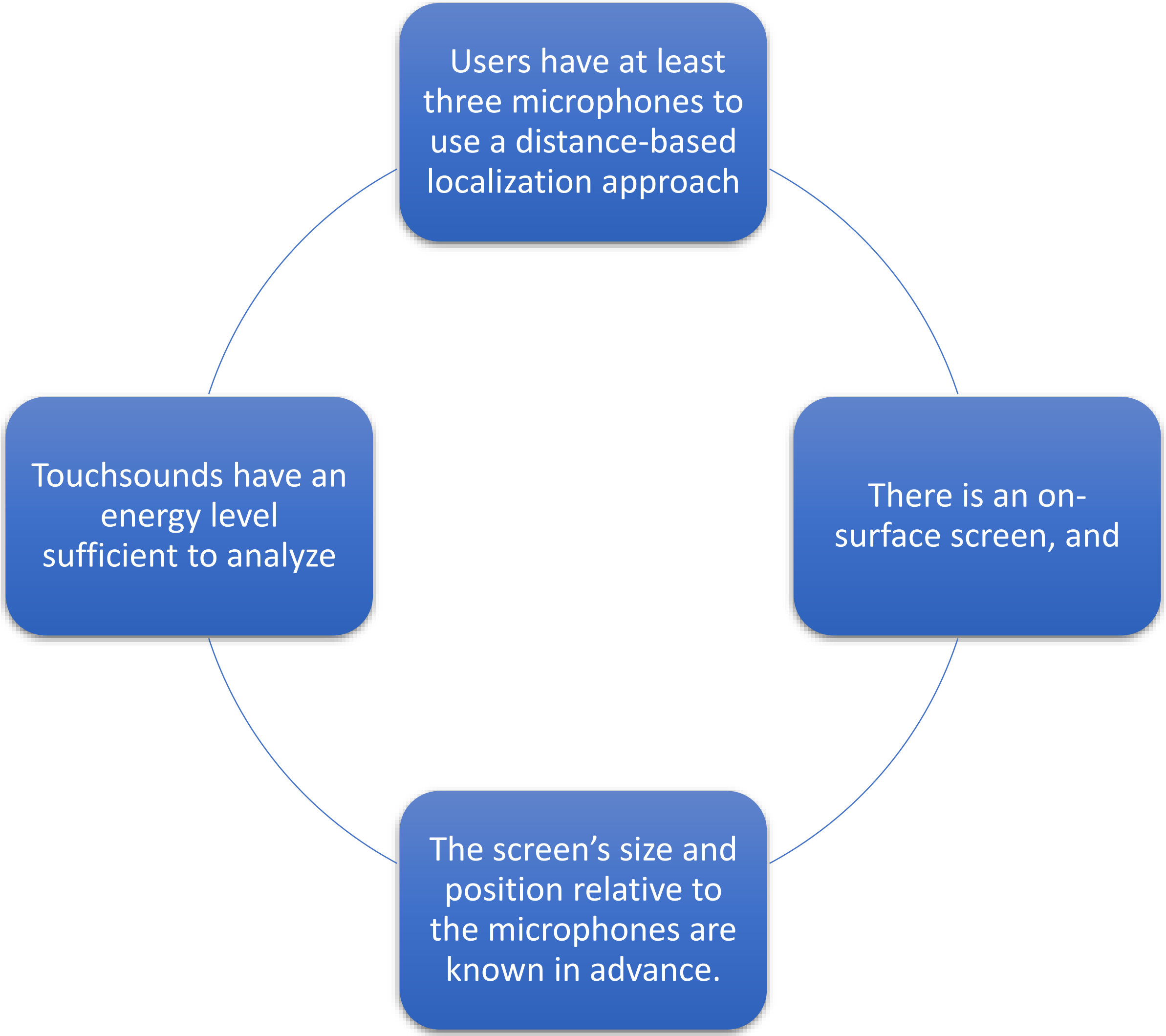
$$T^A(f_i)\text{-}\,T^A(f_j) = D * \left(\frac{1}{V(f_i)} - \frac{1}{V(f_j)}\right)$$

where $T^A(f)$ is the arrival time of the touchsound at frequency f .

Ubitap System Architecture



Ubitap Design



Touchsound detection

- Ubitap uses motion sensors to overcome the problem of noise if a sound-level threshold is used.
- It uses energy level of a touch sound which it compares with a threshold to detect the touch

Arrival time estimation

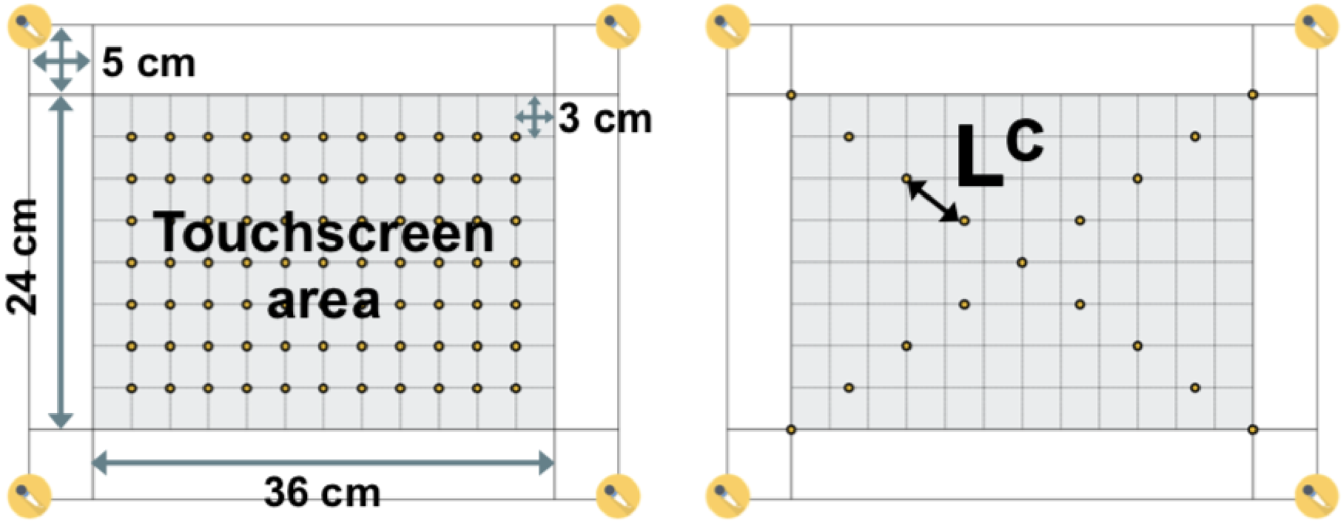
- Ubitap does not use a high-resolution method to detect frequencies as it may compromise responsiveness
- It differentiates between high and low frequency waves and deals separately with them.
- Low-frequency waves
  - Arrive in the form of negative peak
  - Highest energy level
- High-frequency waves
  - Are observed very early => smaller number of samples
  - Can use high resolution methods since sample is smaller

Implementation

- This idea requires minimal hardware.
- The prototype has been tested on Android running smartphones
- Implementation includes capturing raw sensor data using microphones and gyroscopic sensors.
- Configurations
  - Microphones with sampling rate 192 kHz
  - Motion sensors with sampling rate 220 kHz

Evaluation (set-up)

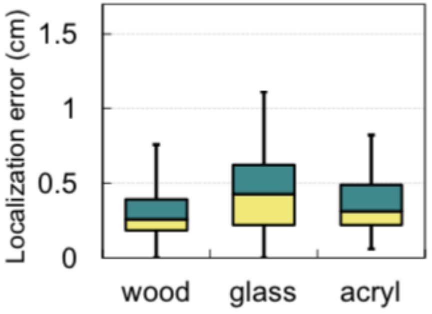
- On-surface touchscreen (36cm X 24cm)
- Portable projector (SK Smart Beam)
- Microphones of smartphones (2 Google Pixels, 2 Google Pixel XLs)
- On a wooden table
- Also included glass mirror and acrylic board
- Requested the user to tap the calibration points



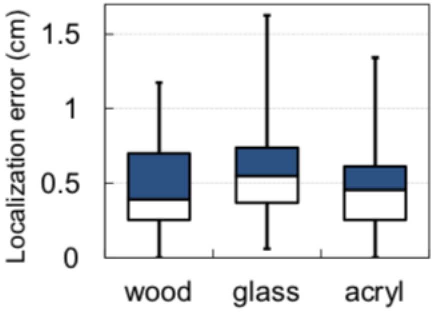
(a) Touchscreen setup. (b) Calibration setup.

Evaluation

- Accuracy test
  - Overall: Satisfies sub-centimeter accuracy as it captures dispersive characteristics of touchsounds
  - Number of microphones: Ubitap provides a great accuracy for greater number of microphones, but has also performed great with the minimal number (3 microphones)



(a) With 4 microphones.



(b) With 3 microphnoes.

Evaluation

- Robustness test: inputs in dynamic environmental changes
  - Changes in position of touchscreen ✓
  - Changes in surrounding objects ✓
  - Ambient Noise ✓
- Responsive test
  - Running time of 33.4ms
  - Shows it could be useful in variety of applications
- Usability test
  - Even lower number of calibration points provide higher degree of accuracy
  - Prior works trade-off between accuracy and usability

Potential Limitations

- Curvature/irregularity in surfaces
- Large obstacles
- Smaller display area
- Close proximity between microphones
- Touch tool variations

References

- Kim Hyosu, Anish Byanjankar, Yunxin Liu, Yuanchao Shu, and Insik Shin. "UbiTap: Leveraging Acoustic Dispersion for Ubiquitous Touch Interface on Solid Surfaces." In Proceedings of ACM Sensys, 2018.