MobiSys'16

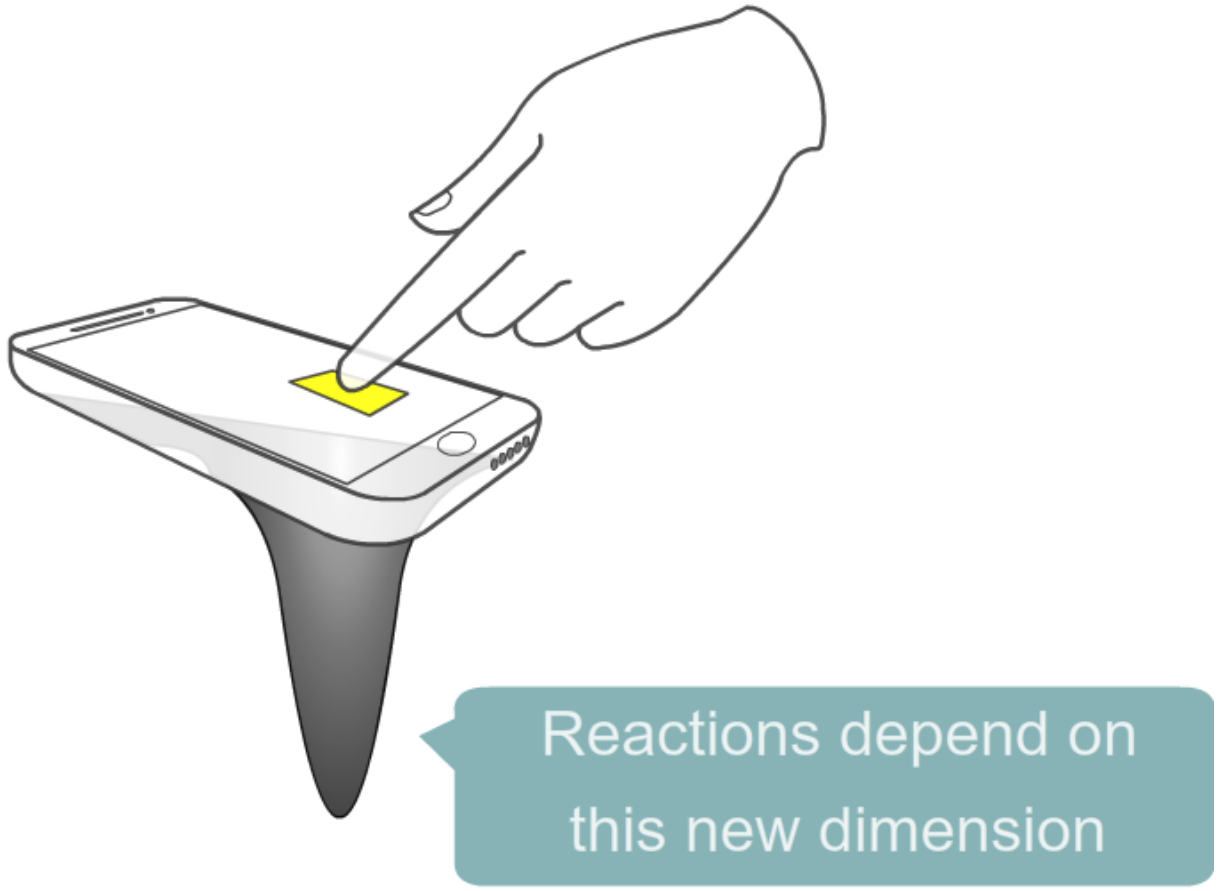
Expansion of Human–Phone Interface By Sensing Structure-Borne Sound Propagation

Yu-Chih Tung and Kang G. Shin
The University of Michigan

The small but indispensable

The other dimensions

- Duration
- Click #
- Direction
- Force



The force

Perspectives

3D Touch

Other Devices?

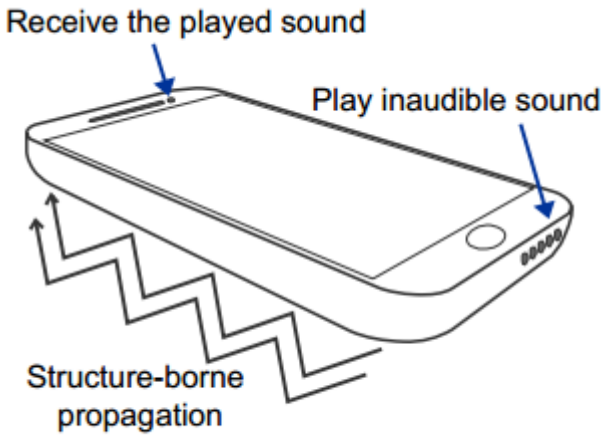
ForcePhone

Force sensing in any smartphone

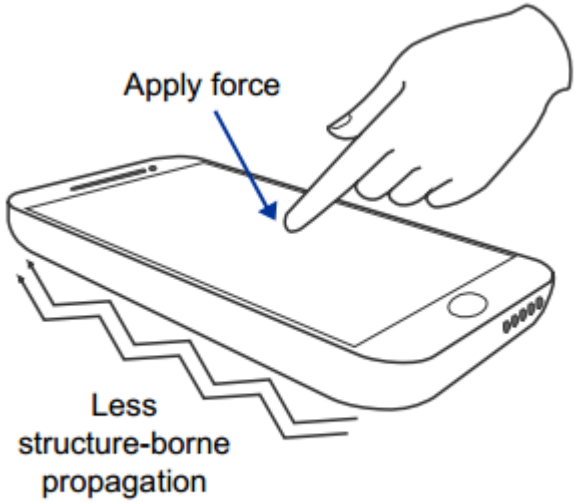
- Requires only built-in sensors
- Enables force sensing over the whole phone
- Provides comparable accuracy to 3D Touch

Force sensing in any phone creates ecosystem of utilizing force sensing

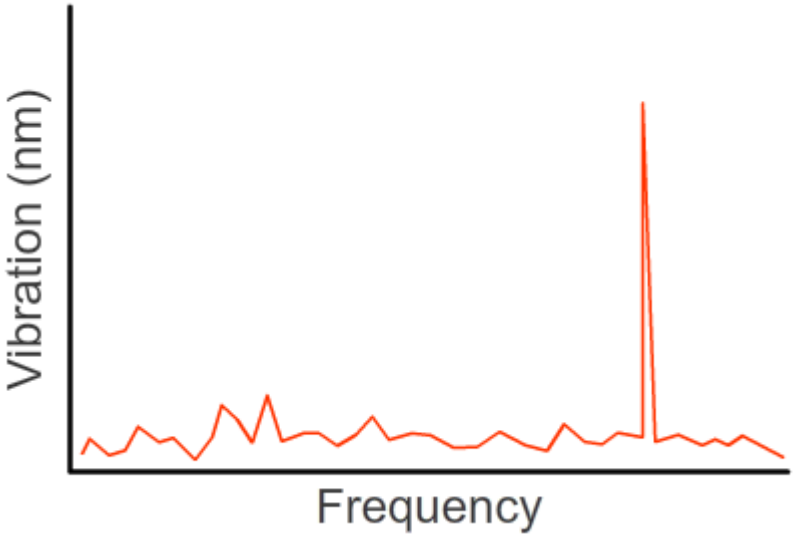
Structure-borne propagation

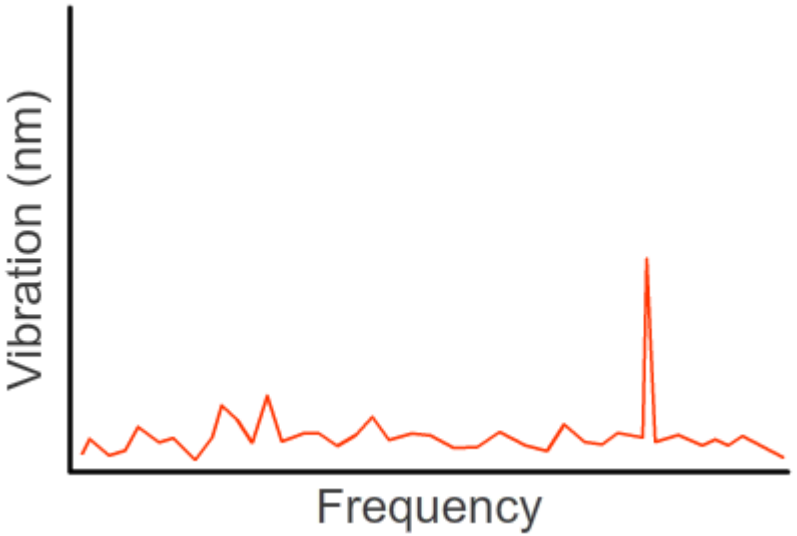


(a) No force

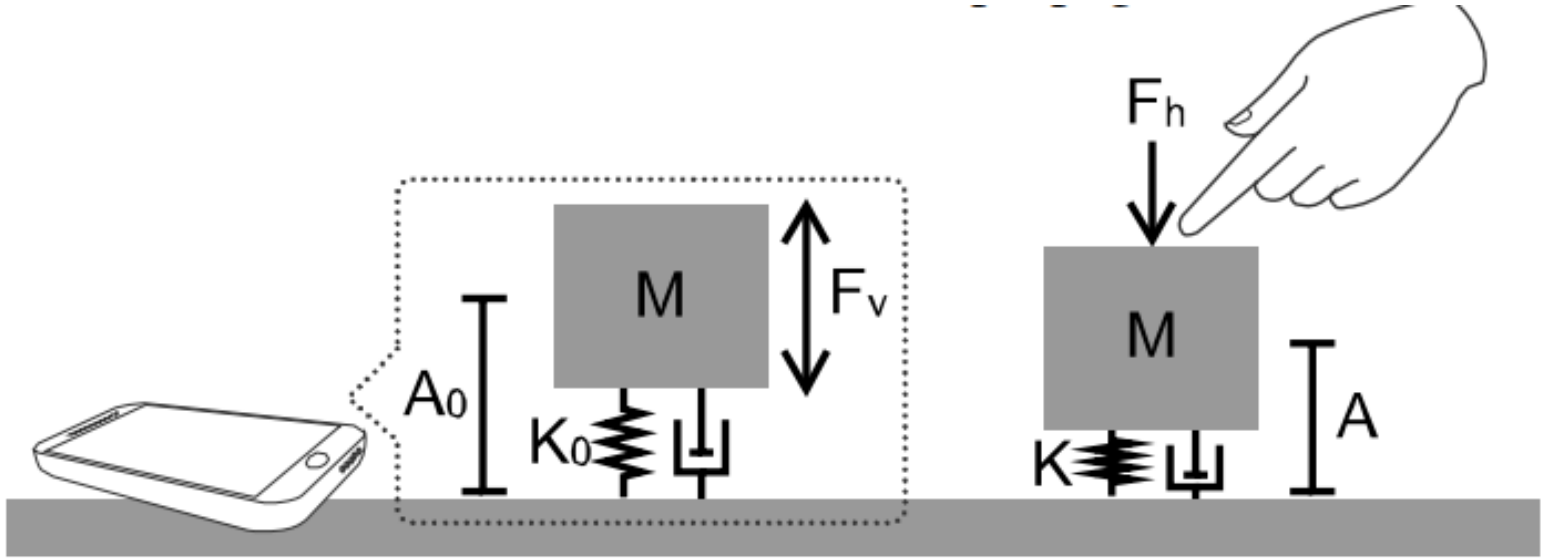


(b) Force applied





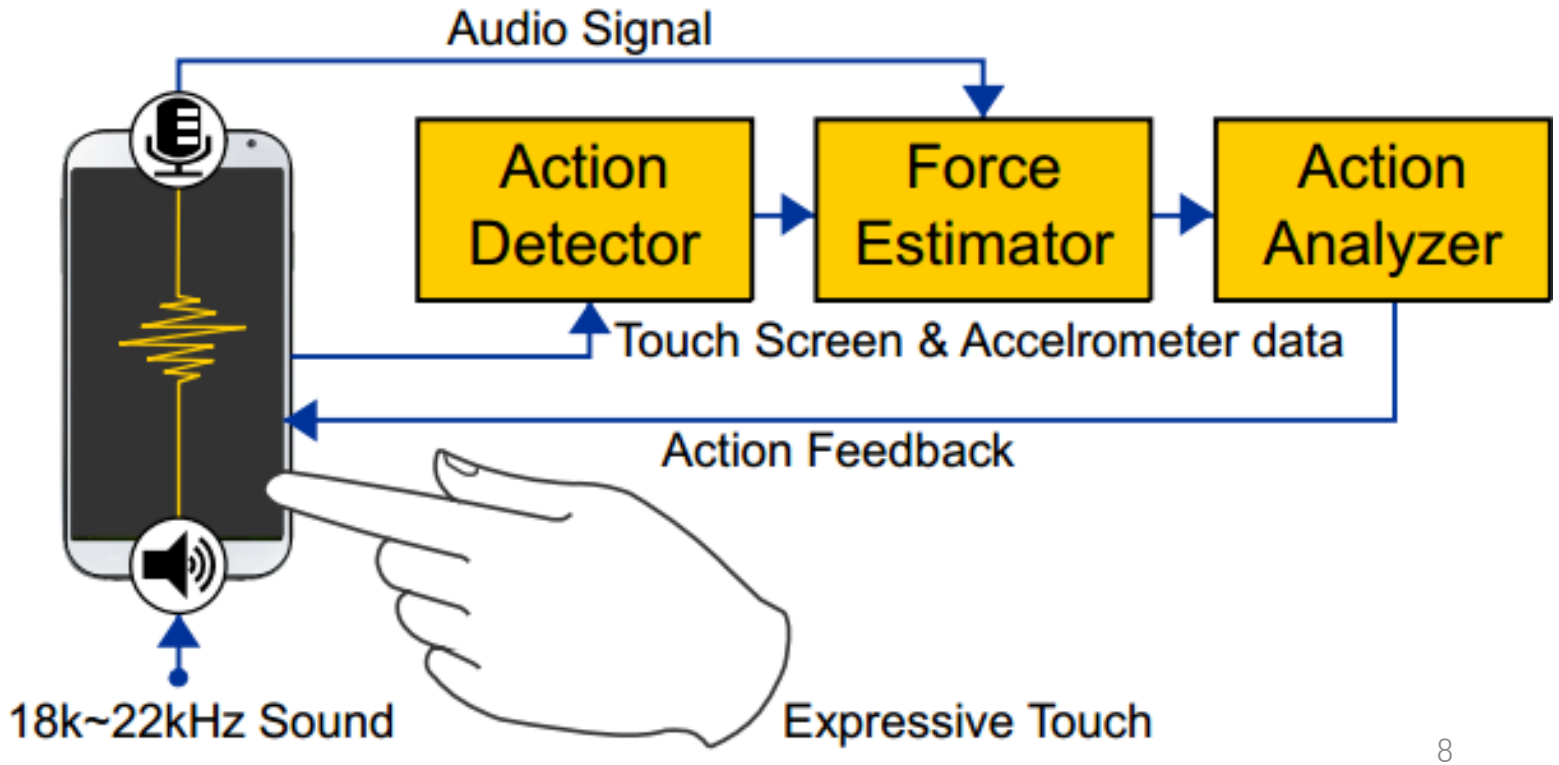
Structure-borne propagation



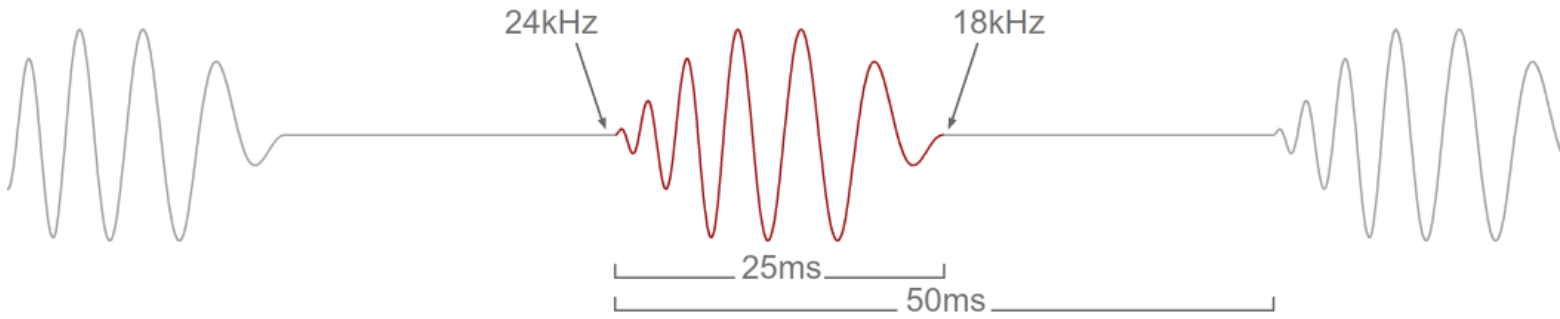
$$\frac{1}{2}K_0A_0^2 = \frac{1}{2}KA^2 = \frac{F_h}{A_0 - A}A^2$$

SYSTEM DESIGN

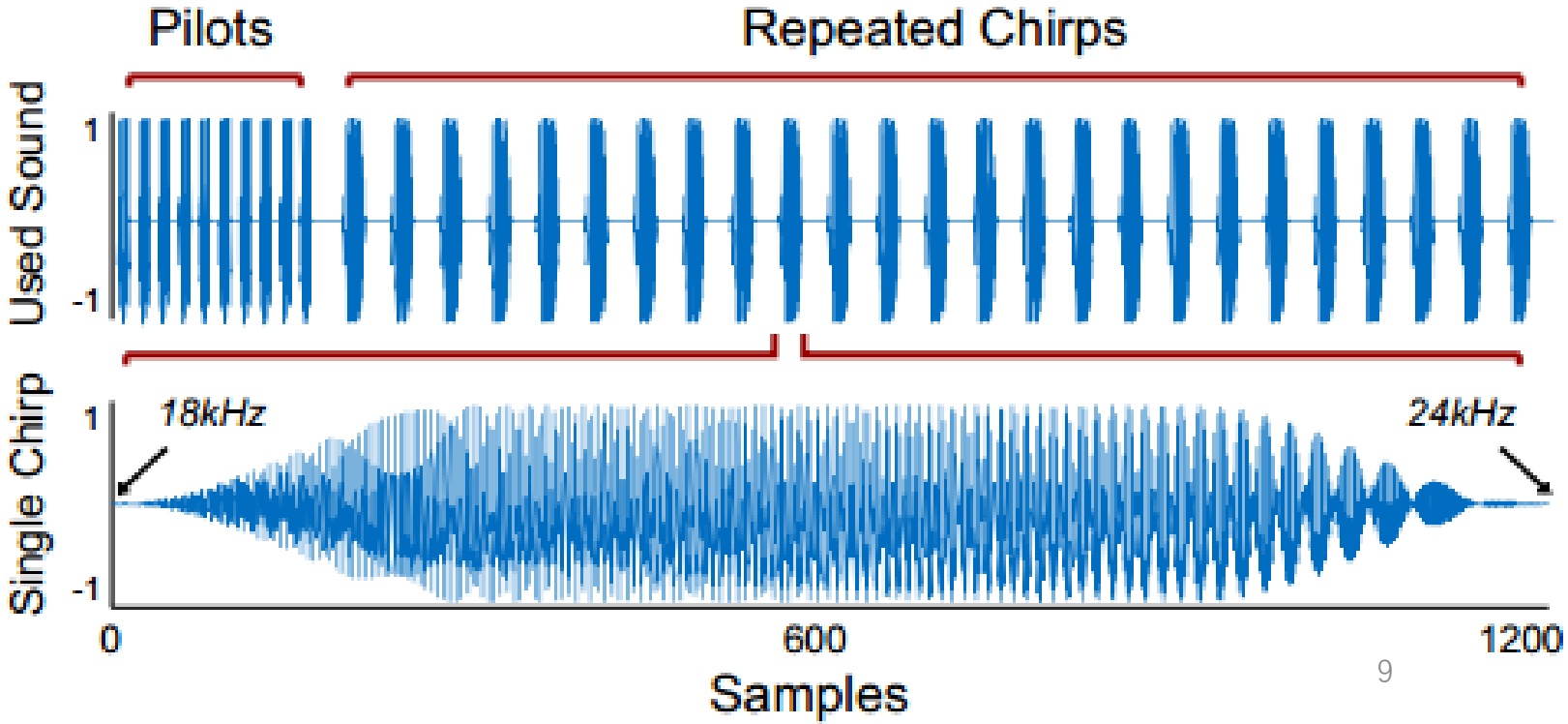
- Sound Selection
- Estimation of Applied Force
- Squeeze Detection



1. Sound Selection

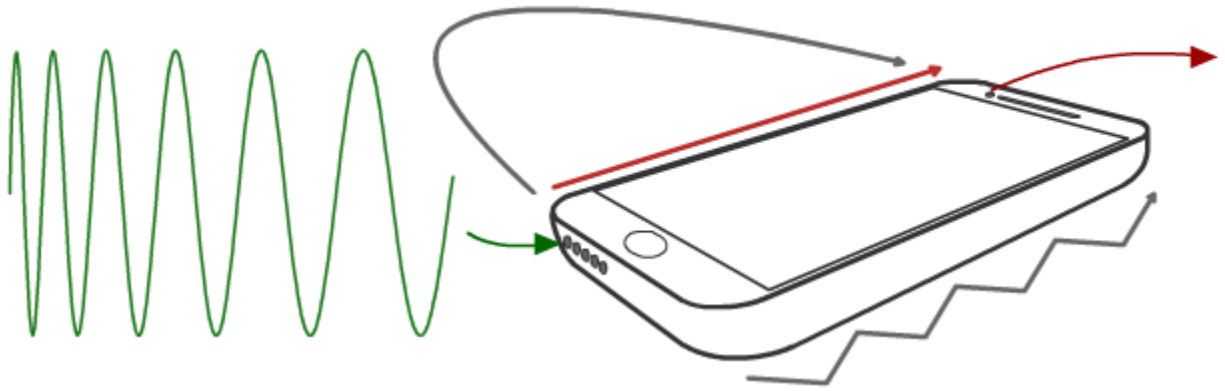


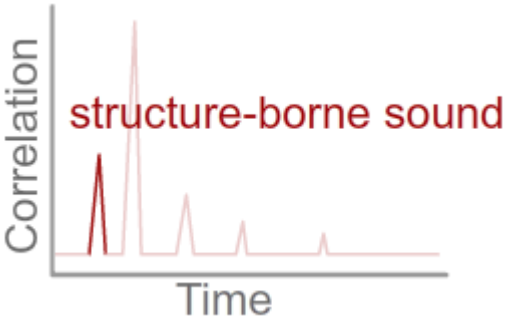
- 18kHz to 24kHz
- Frequency leakages
- Played every 50ms
- Time synchronization

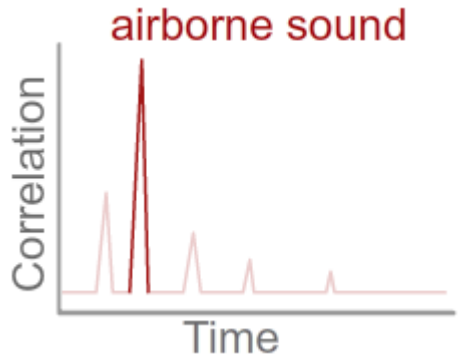


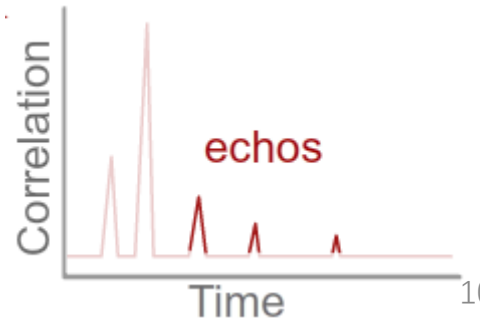
2. Estimation of Applied Force

- Identification and removing of noise
  - combination of structure-, air-borne and echo
  - sound usually travels 100x faster in a solid phone
  - 20 samples ahead of the airborne propagation

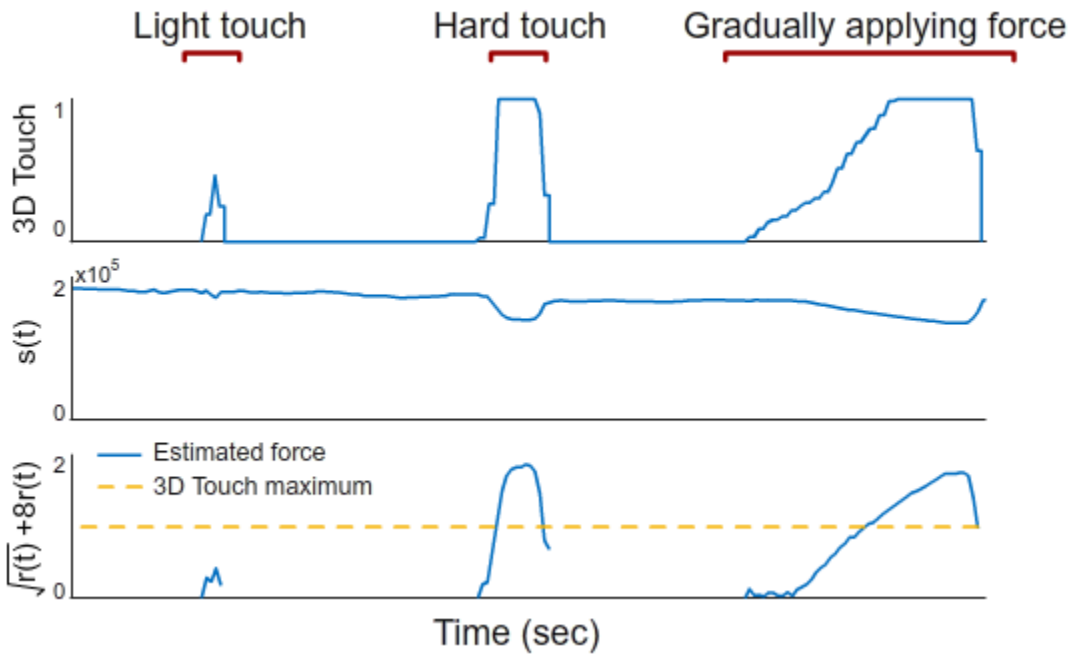








2. Estimation of Applied Force



$s(t)$: the sound correction at time t

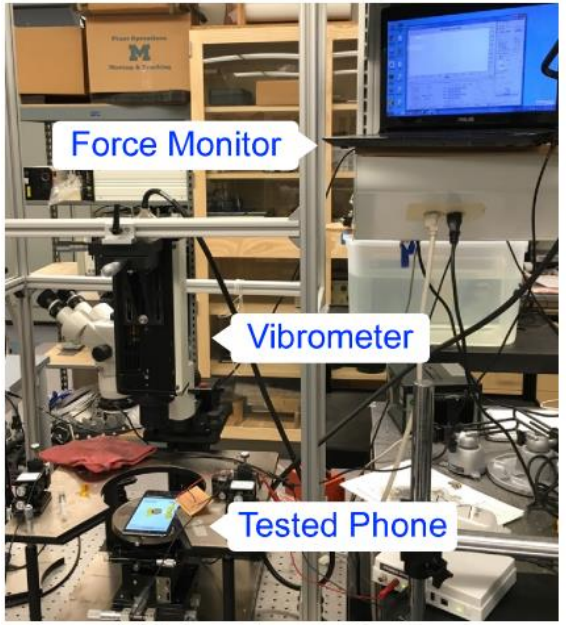
$$r(t) = \left|(s(t) - s_{start})/s_{start}\right|$$

$$\text{Estimated force} = \sqrt{r(t)} + 8r(t)$$

2. Estimation of Applied Force

- Calibration
  - parameters of f(t) varies with the location of force applied on the phone

(a) Calibration UI (b) Signal change $\overline{r(t)}$ of 500g force



(a) Experiment Setting

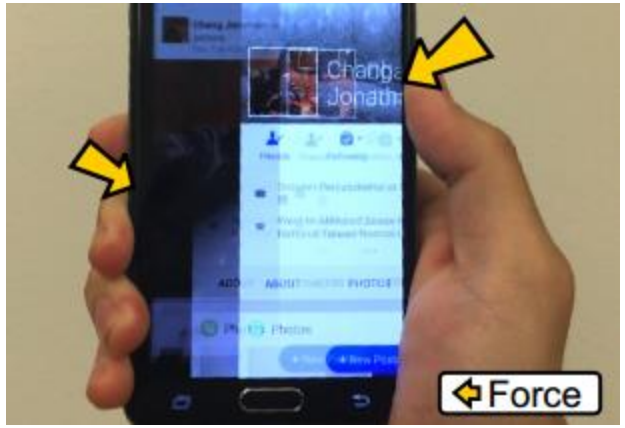
(b) Laser Focus Location

(c) External Force Sensor

3. Squeeze Detection

- Turns off our squeeze detection when there is a large phone movement and the signal is noisy.

- The squeezable back function is made to respond only to a predefined squeeze behavior.
  - Double squeezes applied
  - The entire squeeze process is assumed to complete in 1.5 seconds



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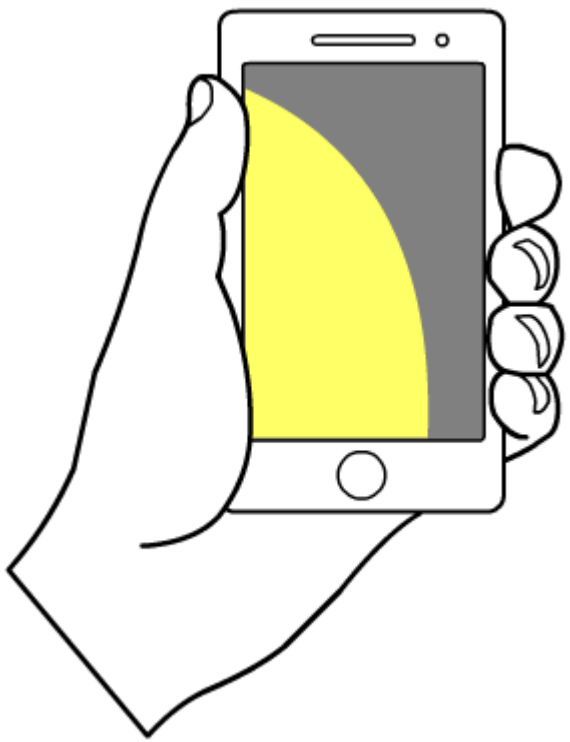
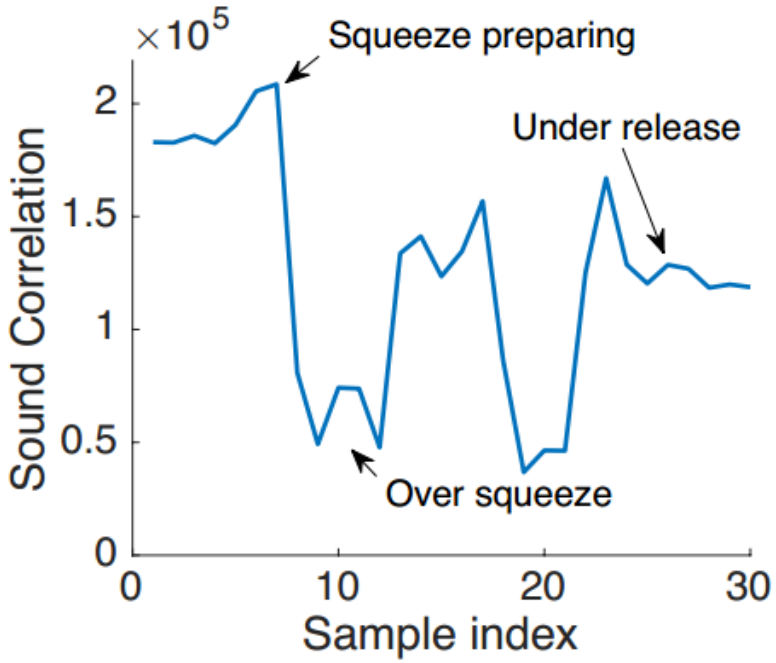
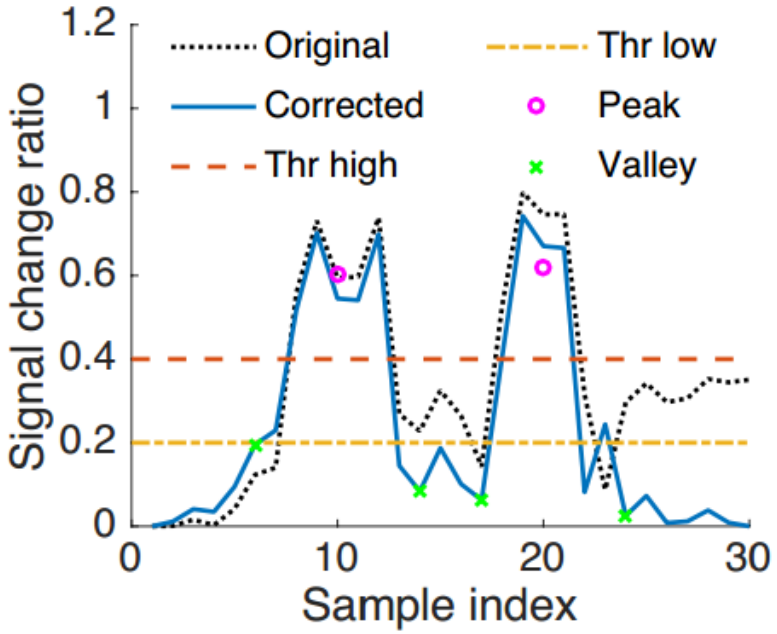




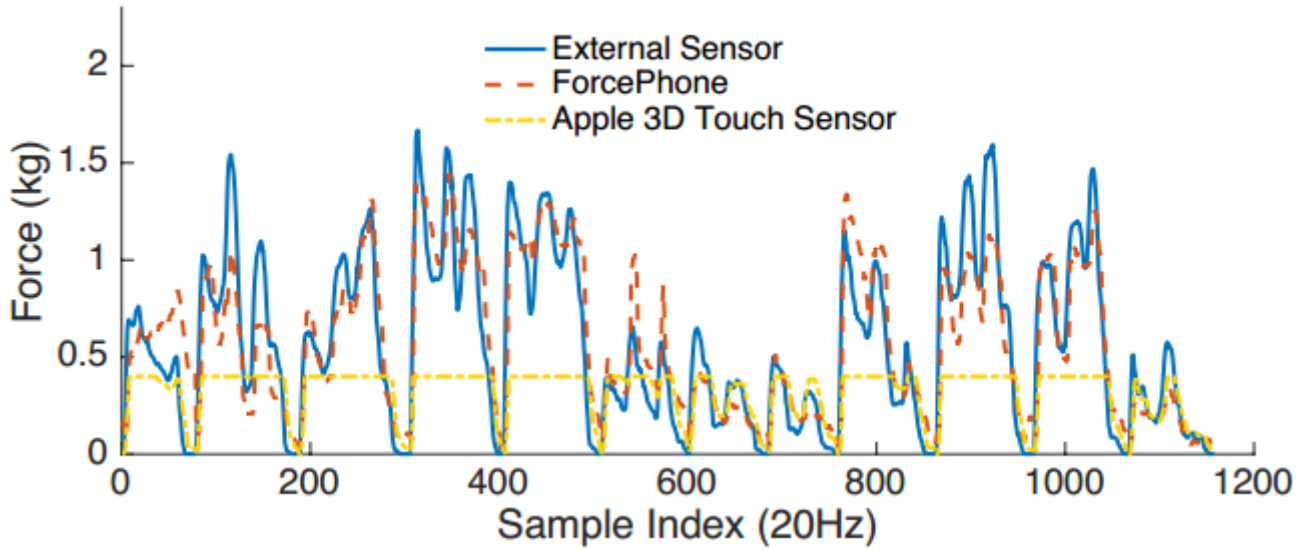
(a) Squeeze response



(b) Squeeze detection

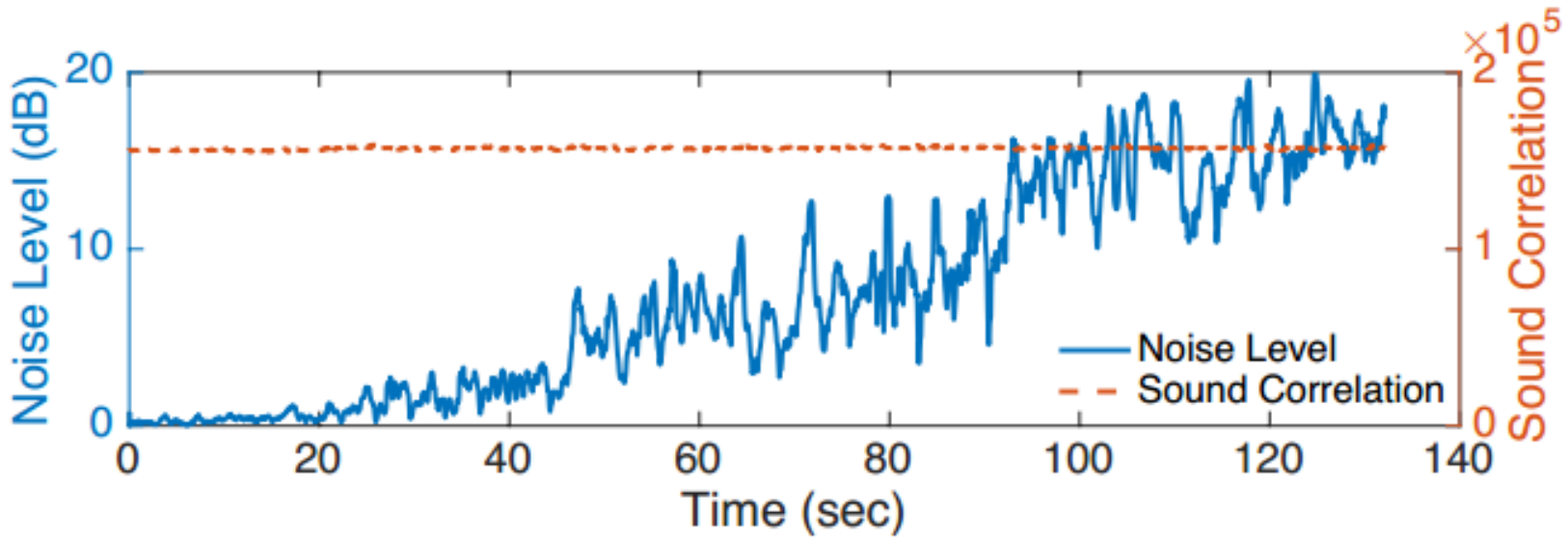
Evaluation

Accuracy of force estimation



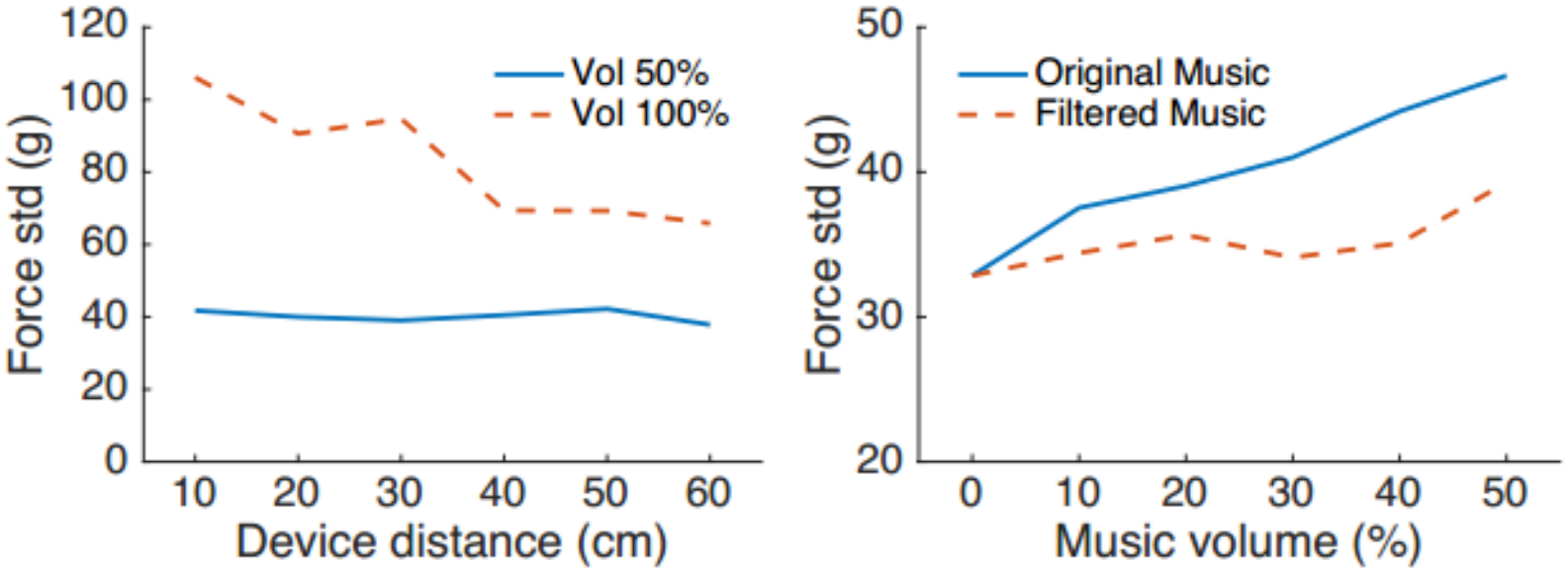
- 12 touch events with different amounts of applied force are plotted. The force estimated by ForcePhone provides high correlation with the ground truth estimated by using our external force sensors.

Resistance to background noise



- Music (i.e., noise) played by a laptop 20cm away from the device under test has limited effect on the sound correlation even if the noise level is increased to 20dB higher than the used chirps.

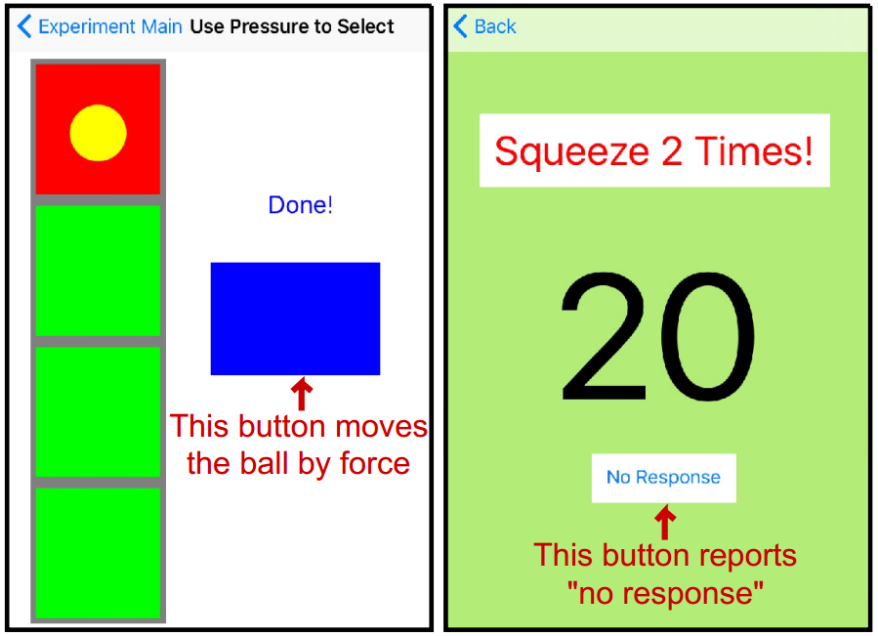
Resistance to inter-device and self interferences

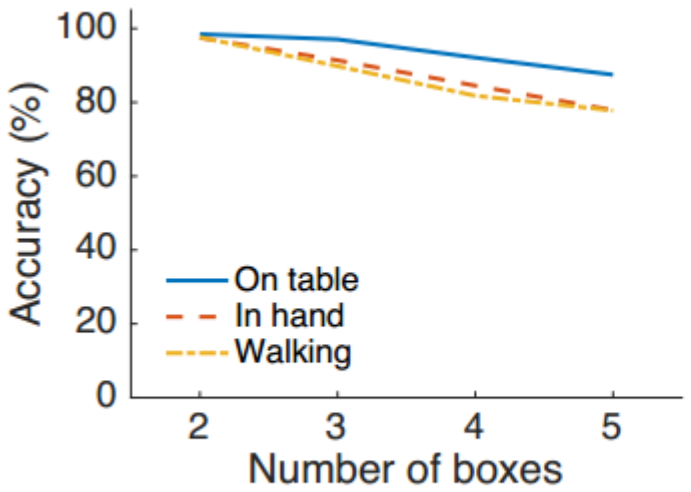


(a) Inter-device interference (b) Self interference

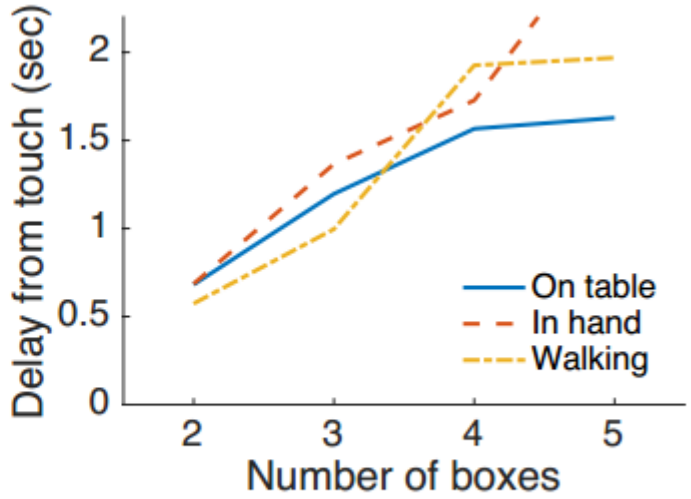
- The variation of sound correlation for each second is used to indicate the error when another device is running *ForcePhone* or a music is played on the same device.

Usability Test





(a) Accuracy



(b) Delay

Users Study of Proposed Apps

Questions	Strongly disagree /Disagree	No op- tion	Strongly agree /Agree
Hard-pressed option is helpful	0	0	21
Hard-pressing(3D Touch) is responsive	1	1	19
Hard-pressing is responsive	0	1	20
Ball-moving game is interesting	0	3	18
Moving ball is responsive	2	4	15
Squeezable back is helpful	1	2	18
Squeezing is responsive	2	1	18
False detection is acceptable	4	7	10

Table 3—App study results.

Conclusion

- Contribution
  - Design of force-sensitive and squeezable interfaces via structure-borne sound propagation
  - Detailed evaluation, intuitionistic exhibition

- Shortcoming
  - Recognition of squeeze operation