ViType: A Cost Efficient On-body Typing System through Vibration

Wenqiang Chen, Maoning Guan, Yandao Huang,
Lu Wang, Rukhsana Ruby, Wen Hu*, Kaishun Wu

Shenzhen University
*University of New South Wales

SECON' 18, Hong Kong

2018/6/26

Background

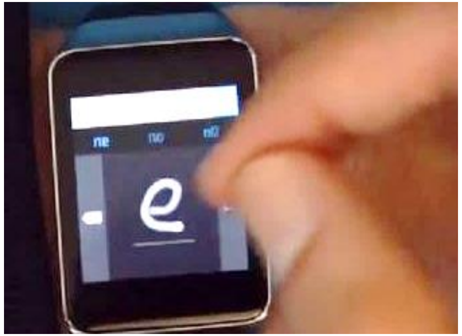
The screen size is getting smaller, and so is the input interface, which makes the interactive experience poorer

Existing Input Methods

01 Simple Typing

Small Size
User Unfriendly

02 Finger Tracking

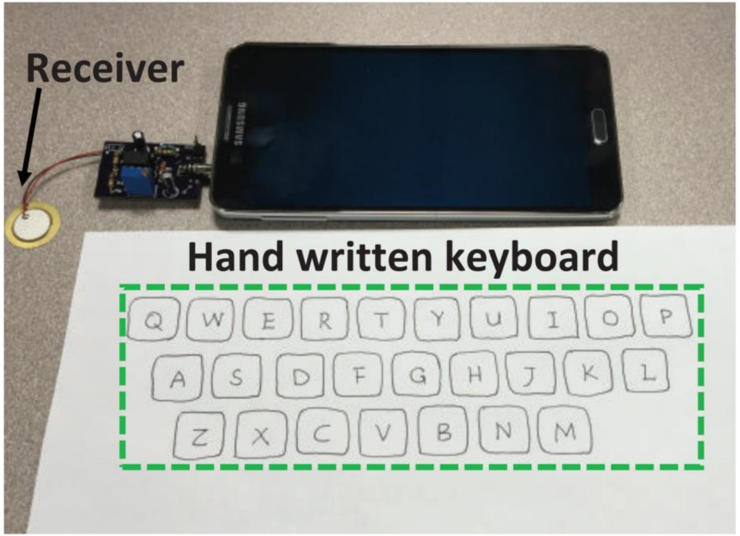


Too Slow

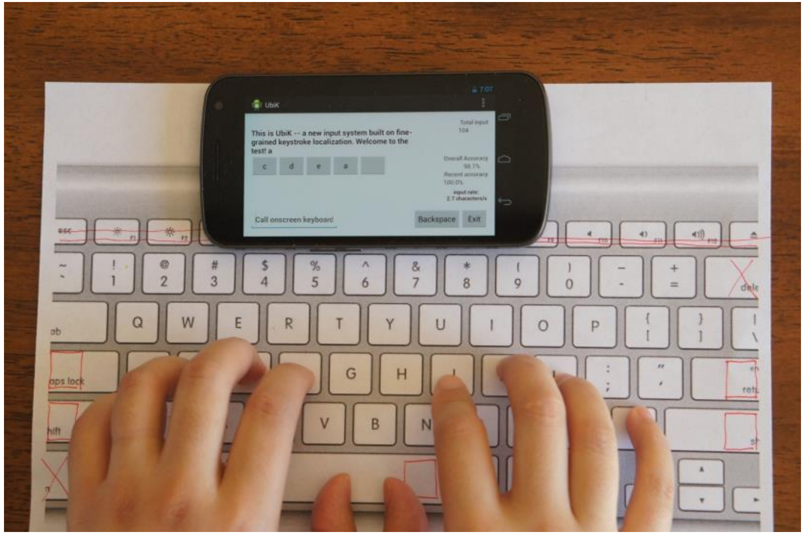
03 Speech Input

Disturbing
Poor Noise Resistance
Sensitive Information

Existing Input Methods



Vibration[1]



Acoustic [2]

1. Yingying Chen, et.al. VibSense: Sensing Touches on Ubiquitous Surfaces through Vibration, IEEE Secon, 2017.
2. Xinyu Zhang, et.al. Ubiquitous Keyboard for Small Mobile Devices: Harnessing Multipath Fading for Fine-Grained Keystroke Localization, ACM Mobisys, 2014.

Related Work

Not Practical

5.5 kHz × 10 Cantilevered piezo films

Armband

Chris Harrison, et.al. Skinput: Appropriating the Body as an Input Surface, ACM CHI, 2010.

How to overcome the limitations of a small screen for smart watch?

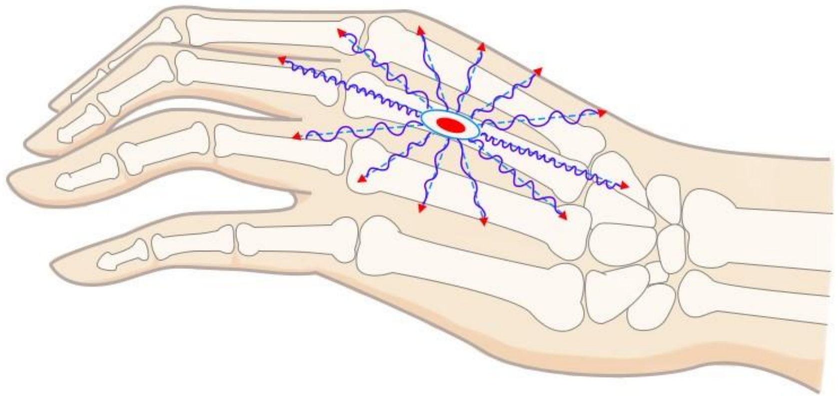
Virtual Keyboard——ViType

On-body typing system with **a speed dial (T9 layout)**

Observation

Attenuation Model

$$A(d)=A_0 e^{-\alpha \times d}$$



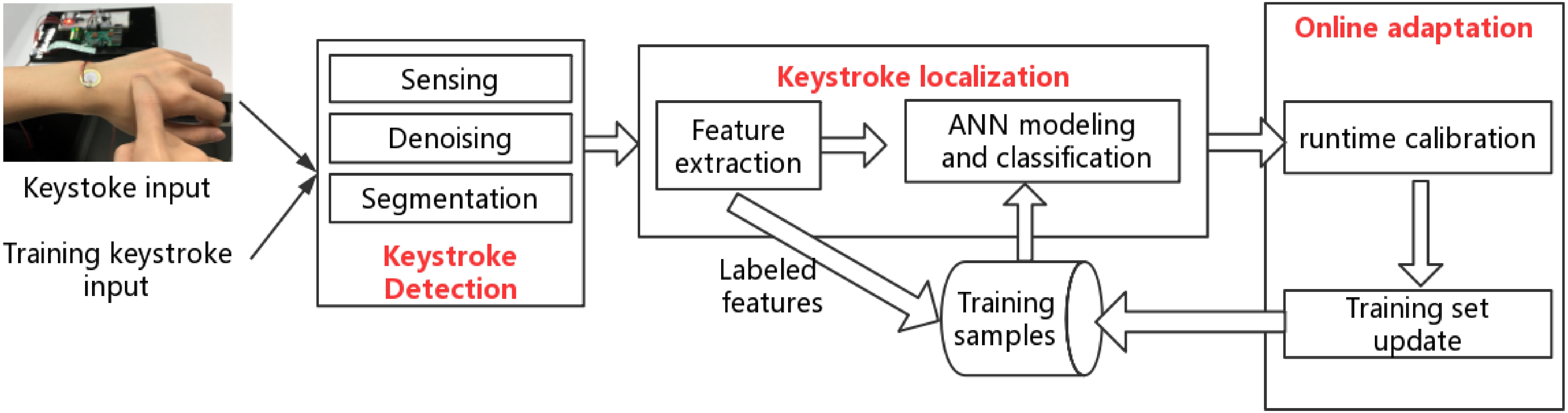
A_0 : the initial amplitude
d : the propagation distance
α : the attenuation coefficient

Tapping on different locations ➡ unique vibration profile

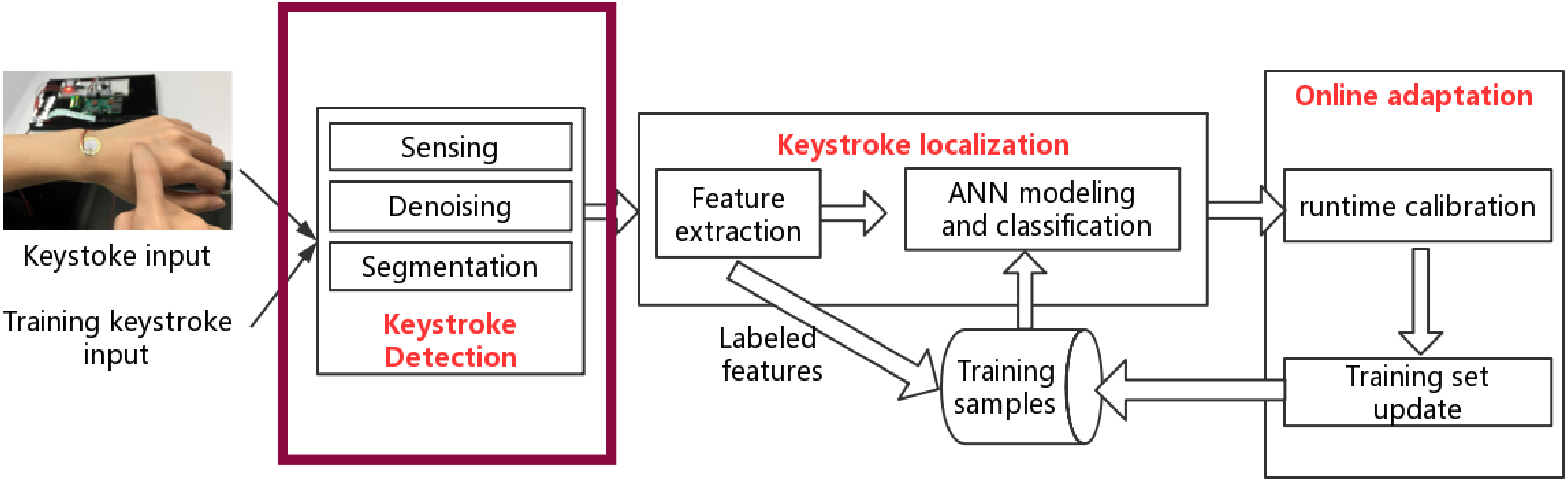
Design Goals and Challenges

1. A Cost efficient systems with **low sampling rate** (600Hz)
2. Sensing with **only one** piezoelectric sensor
3. **Fine-grained** and **robust** under different practical conditions
4. Using **without retraining** after the initial bootstrap

Architecture of ViType



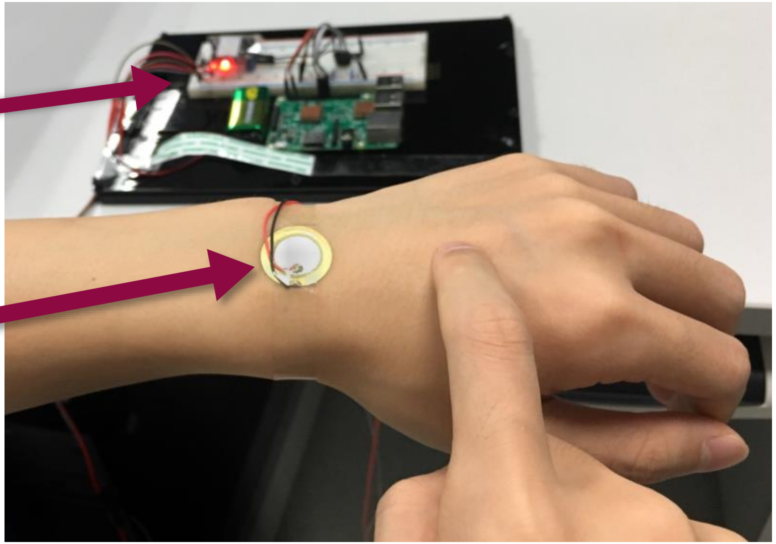
Architecture of ViType



1.A Raspberry Pi with an ADC

2.Piezoelectric ceramic sensor

Diameter： 20 mm
Thickness： 0.4 mm



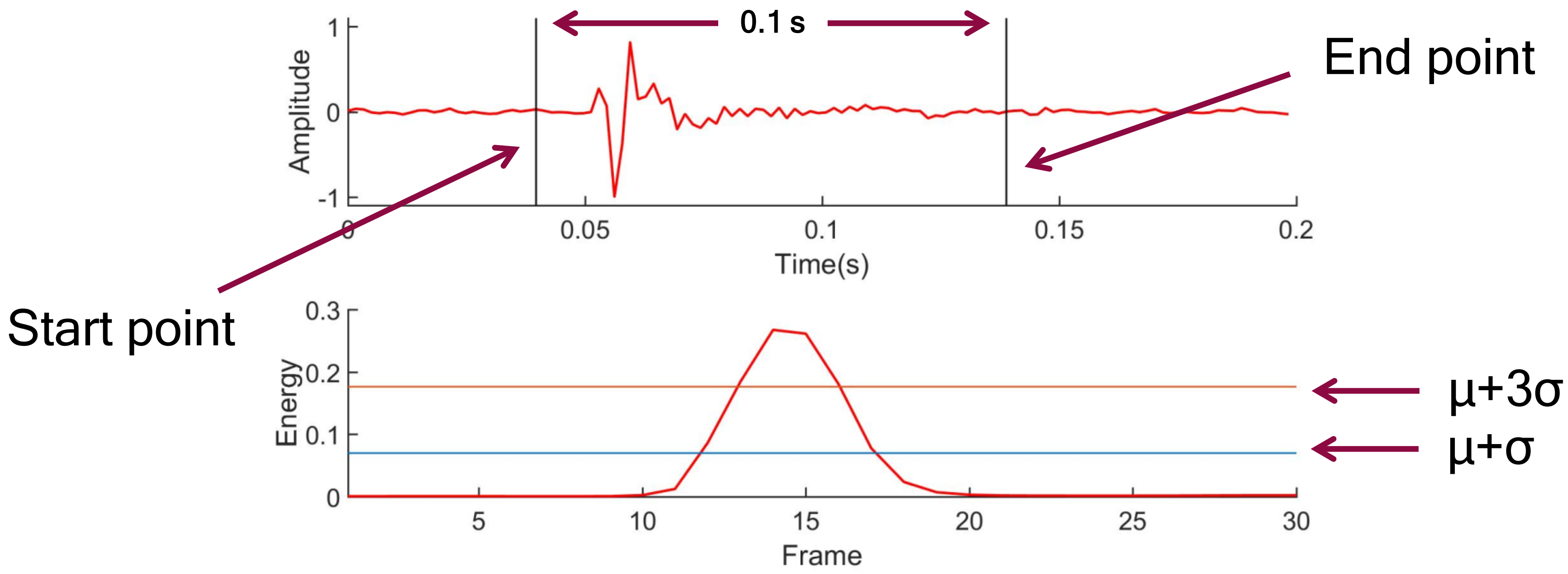
Sensing | **Denoising** | Segmentation

Human mobility

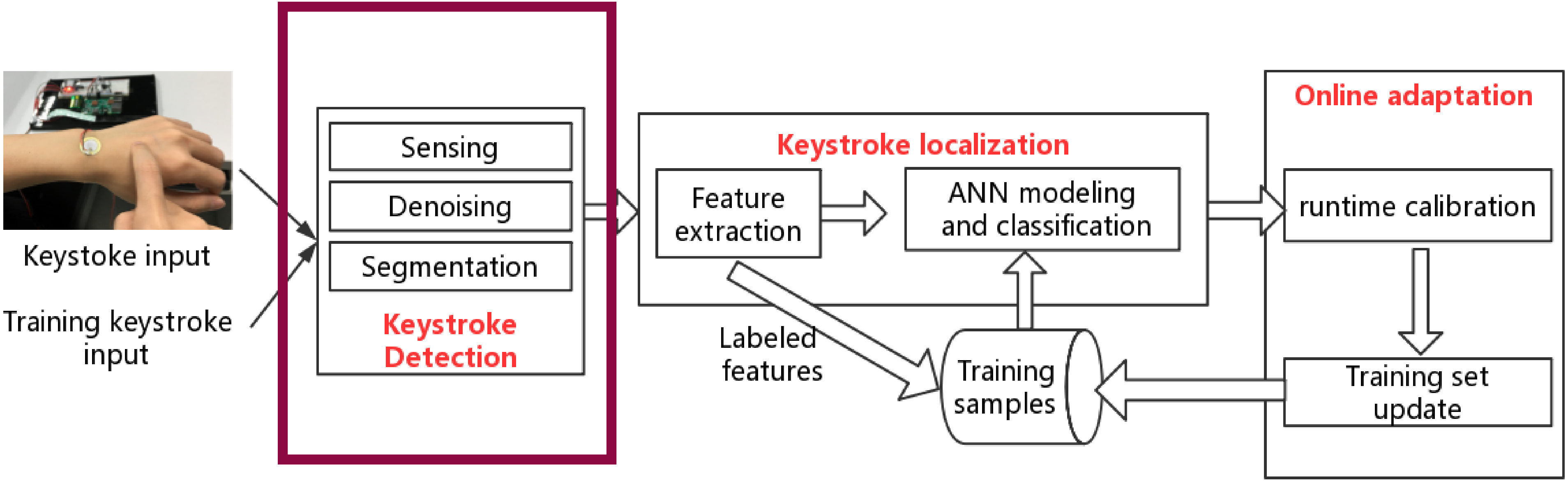
20 Hz Butterworth high pass filter

- To Remove the noise caused by DC & human mobility(less than 10Hz)

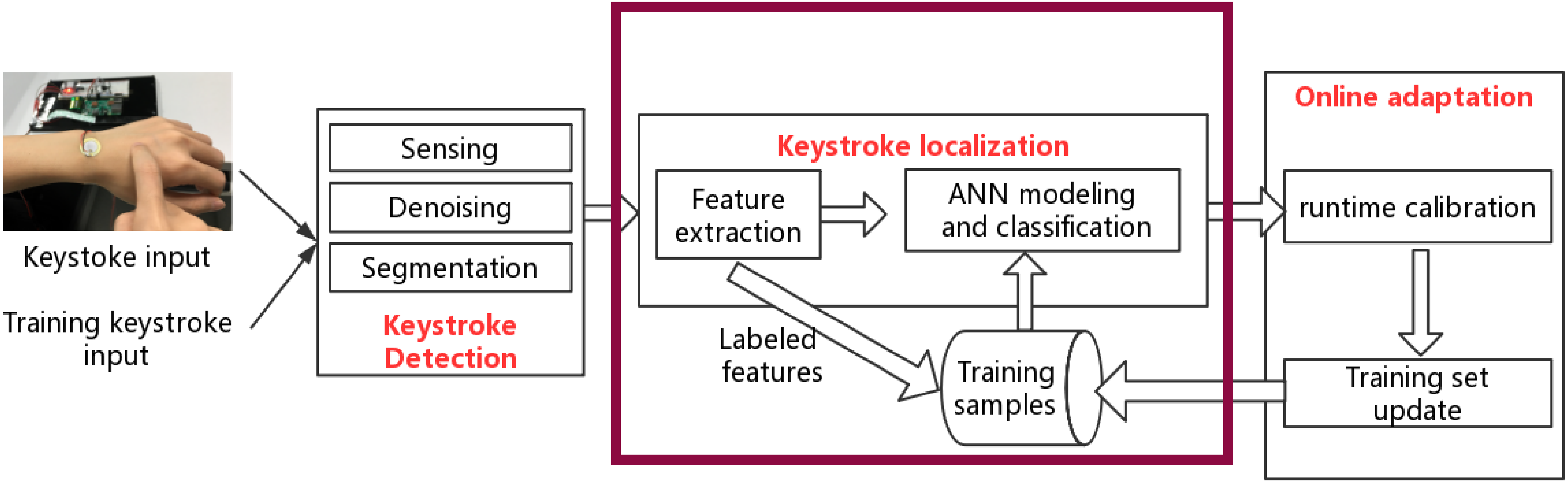
Human mobility


0.1 s
End point
Start point
Amplitude
1
0
-1
0
0.05
0.1
0.15
0.2
Time(s)
Energy
0.3
0.2
0.1
0
5
10
15
20
25
30
Frame
μ+3σ
μ+σ

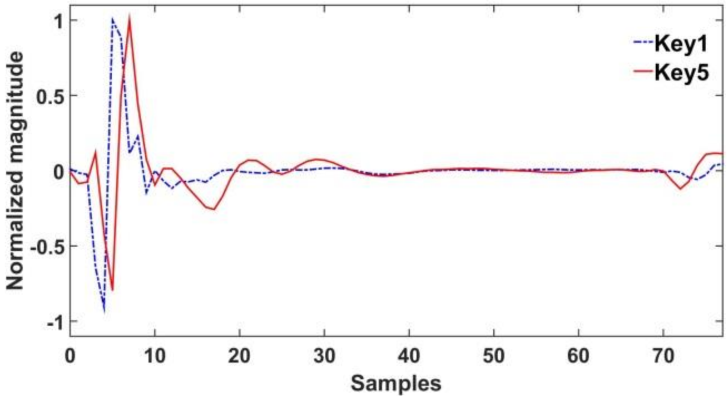
Architecture of ViType

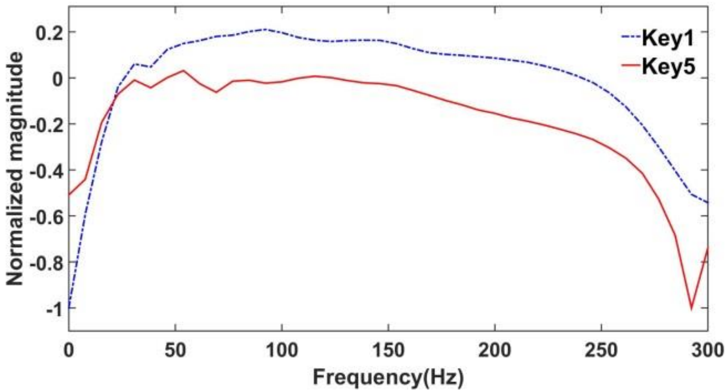


Architecture of ViType



Feature Extraction





Amplitude

(Time Domain)

+

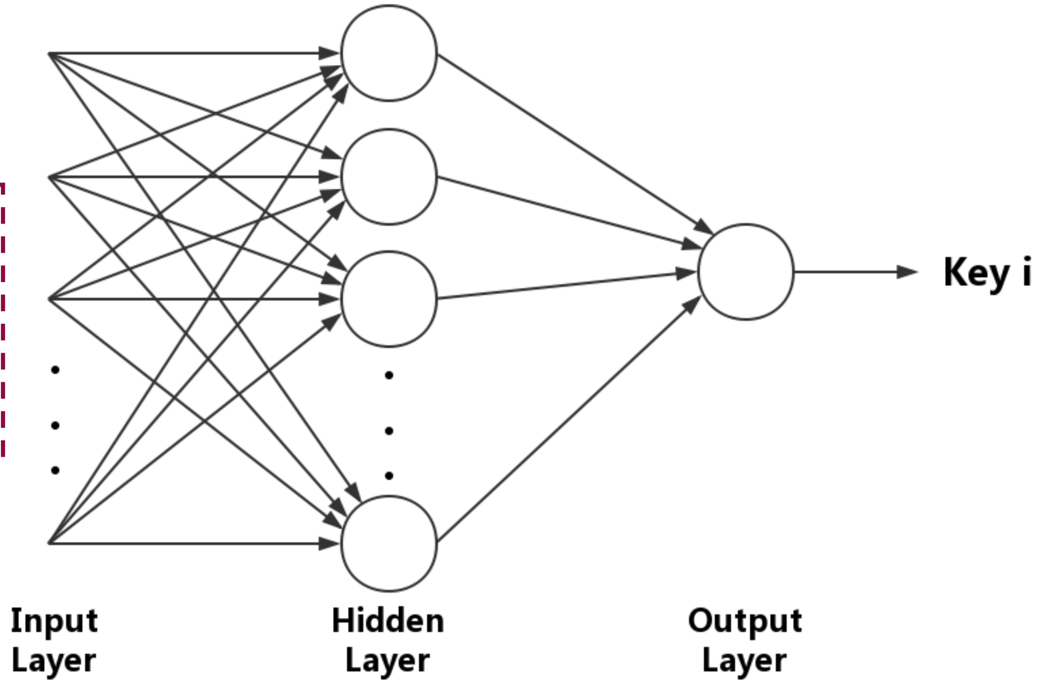
Power Spectral Density (PSD)

(Frequency Domain)

Classification Algorithm

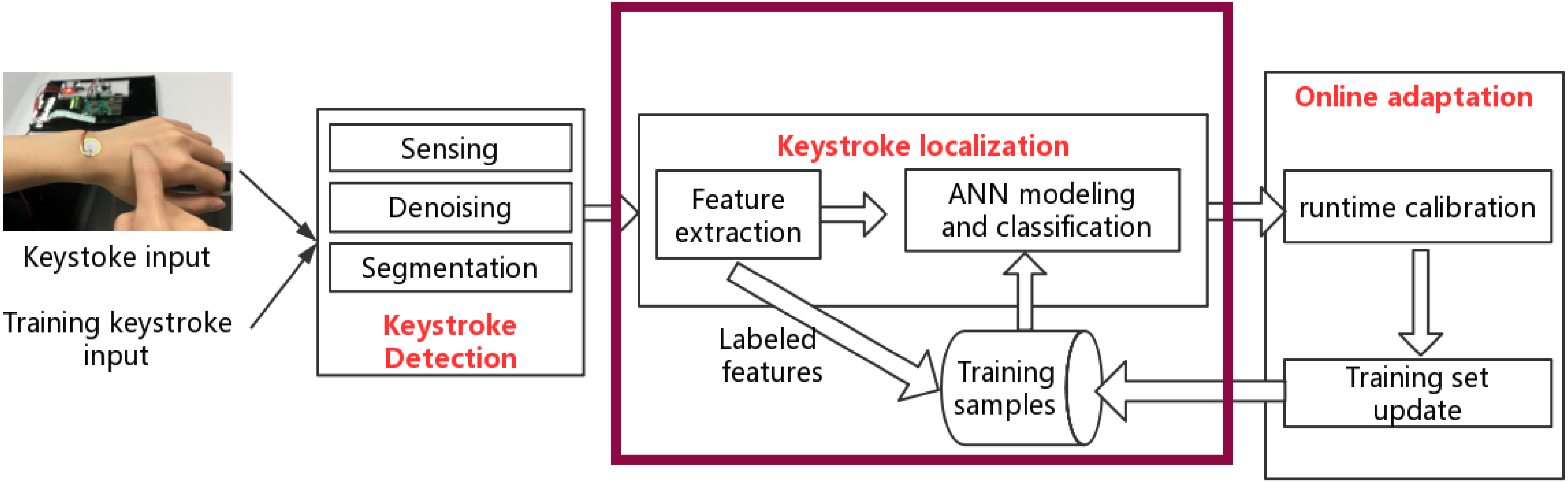
Back propagation Neural Network

Amplitude
+
Power Spectral Density(PSD)

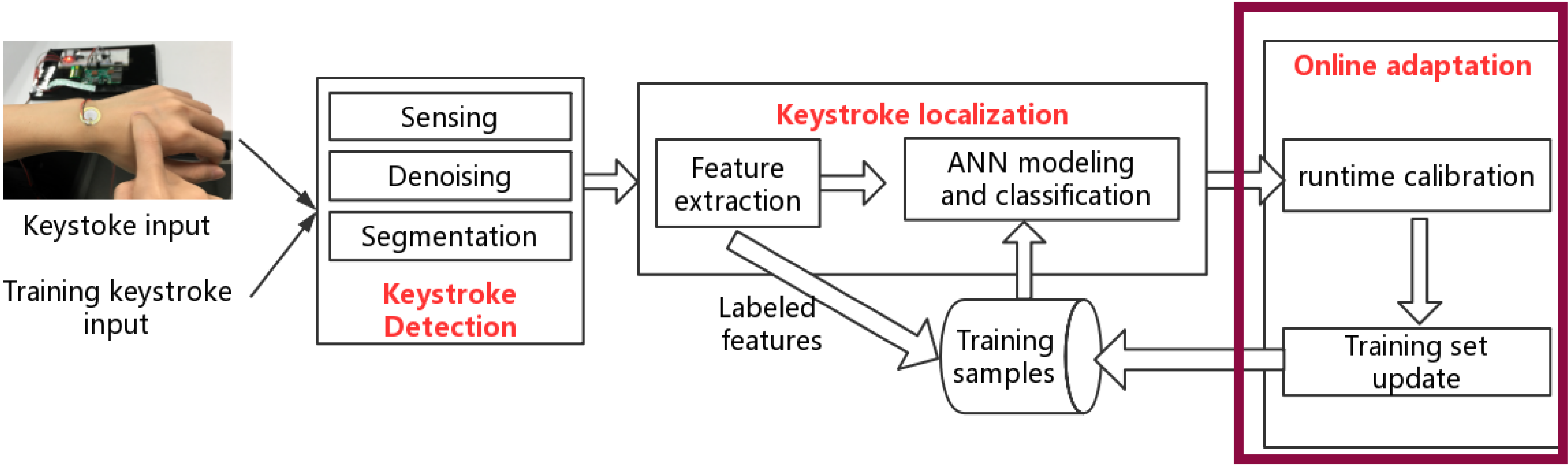


140 nodes

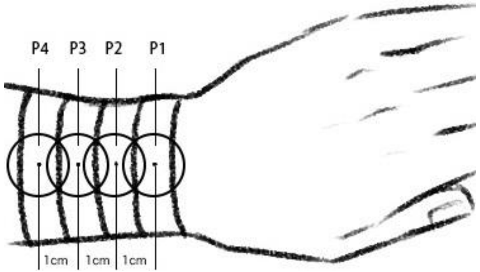
Architecture of ViType



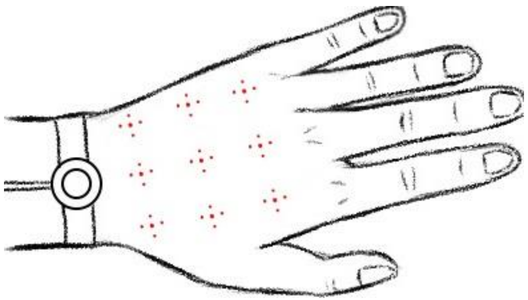
Architecture of ViType



Runtime Calibration and Adaptation



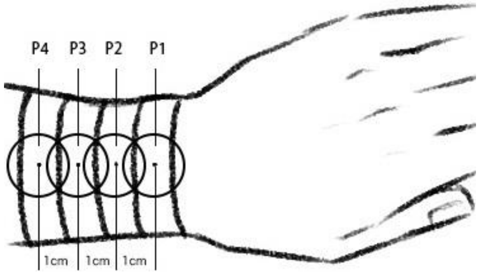
Sensor Displacement



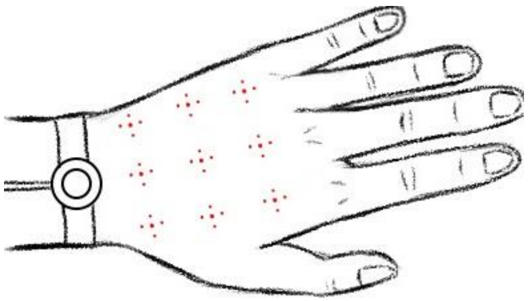
Tap Displacement

How to deal with the deviation?

Runtime Calibration and Adaptation

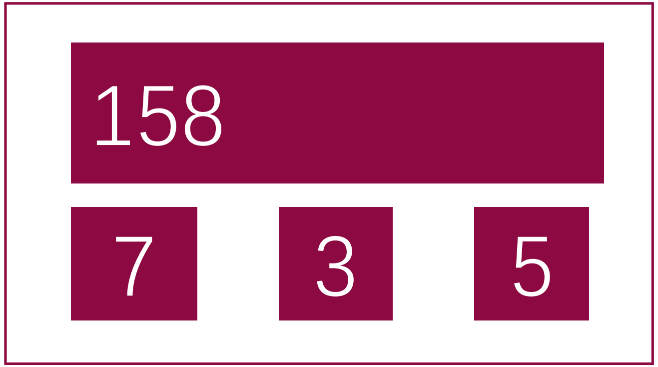


Sensor Displacement



Tap Displacement

Update with candidate keys



Evaluation

1

Accuracy

2

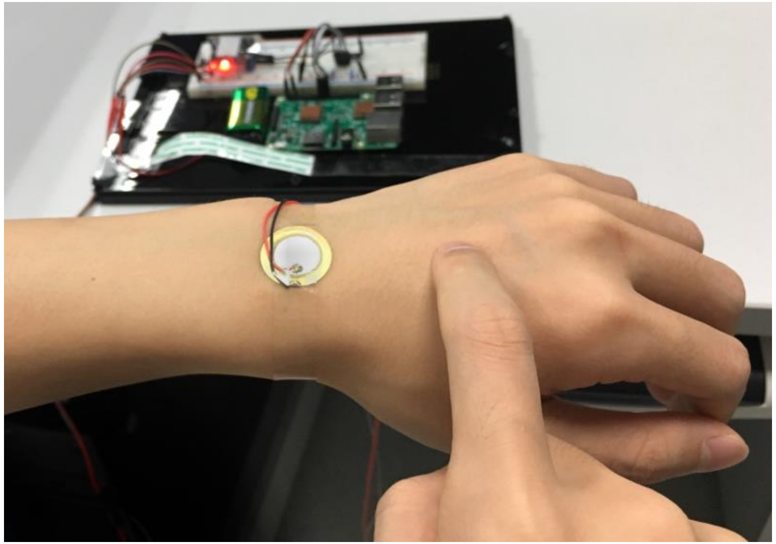
Robustness

3

User Study

Experimental Setup

- 9 virtual keys on T9 layout
- Each participant typed 30 times for each key
- 30 participants collected 8,100 keystrokes



Evaluation

1

Accuracy

2

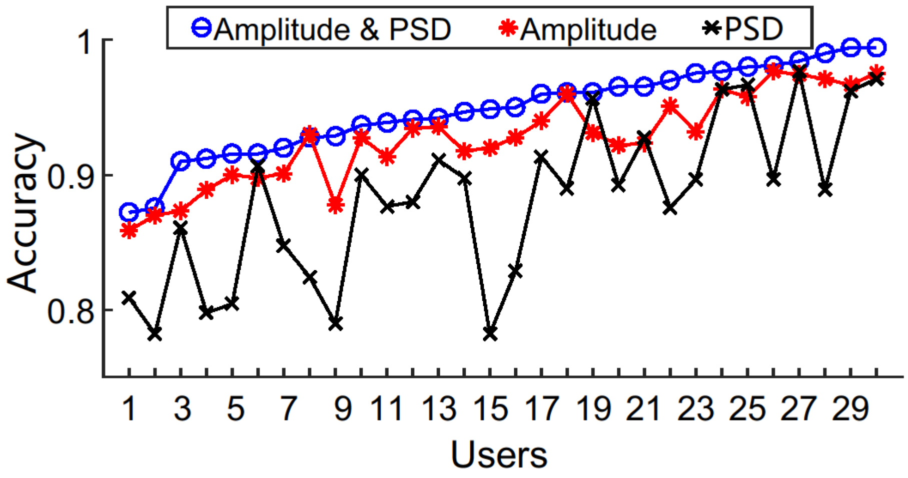
Robustness

3

User Study

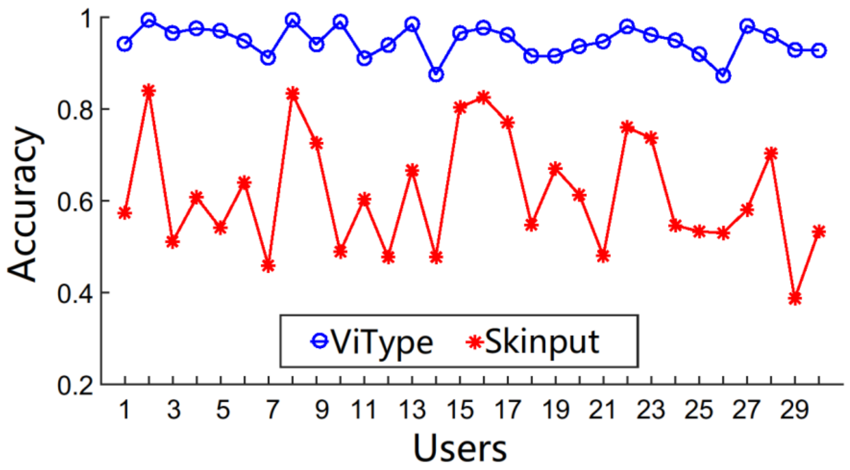
Accuracy——Effect of feature

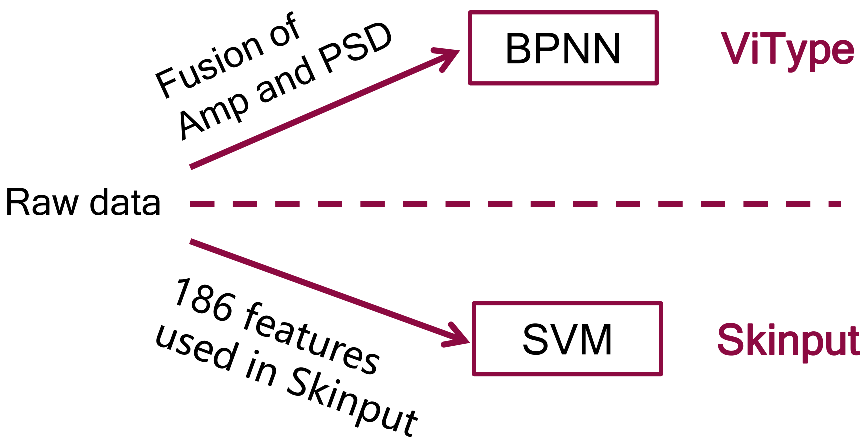
	Key1	Key2	Key3	Key4	Key5	Key6	Key7	Key8	Key9
Key1	0.96	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.01
Key2	0.01	0.94	0.03	0.01	0.01	0.00	0.00	0.00	0.00
Key3	0.00	0.02	0.95	0.01	0.01	0.01	0.00	0.00	0.00
Key4	0.00	0.00	0.01	0.94	0.01	0.01	0.01	0.01	0.01
Key5	0.01	0.01	0.01	0.01	0.94	0.01	0.01	0.01	0.01
Key6	0.00	0.01	0.01	0.01	0.01	0.95	0.00	0.01	0.01
Key7	0.01	0.00	0.00	0.01	0.01	0.00	0.96	0.01	0.00
Key8	0.01	0.00	0.01	0.01	0.01	0.01	0.00	0.95	0.01
Key9	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.95



The average classification accuracy is 94.8%.

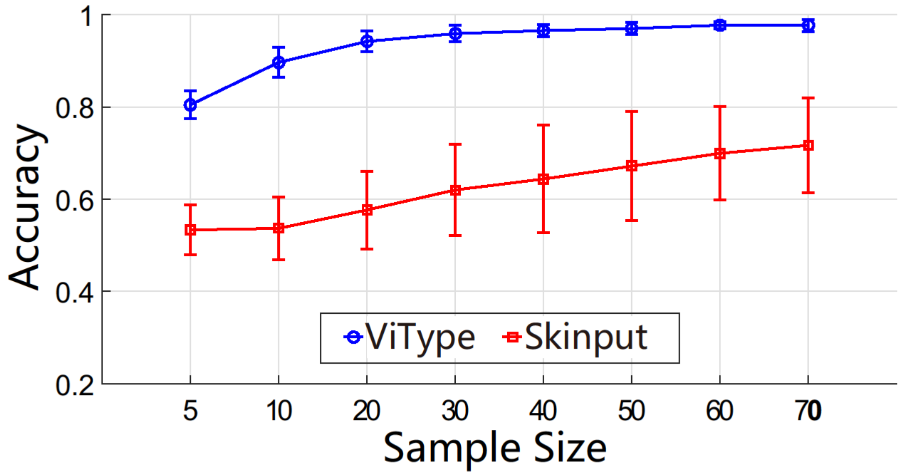
Accuracy——Comparison with Skinput





ViType outperforms Skinput 1.5X.

Accuracy——Impact of Training Set Size



Baseline accuracy: 94.8%

Training set size enlarge from 5 to 20, the accuracy rise from 80.9% to 94.8%.

Evaluation

1

Accuracy

2

Robustness

3

User Study

Evaluation

1

Accuracy

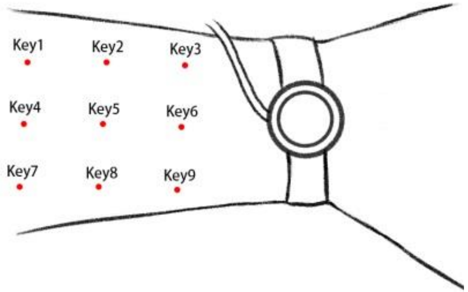
2

Robustness

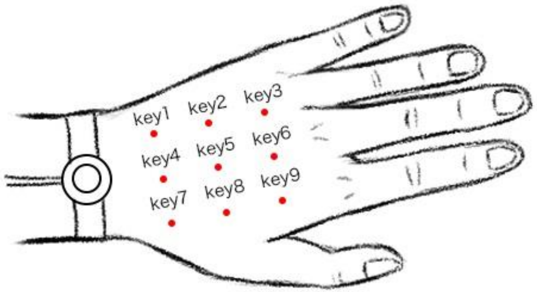
3

User Study

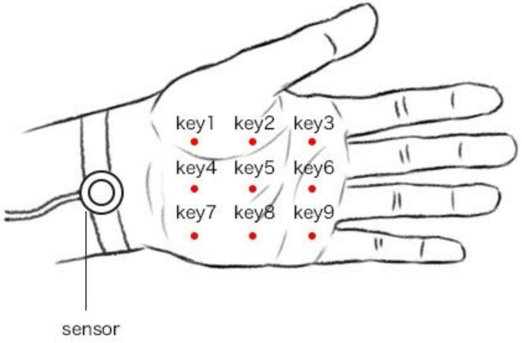
Robustness——Location setting



94.9%



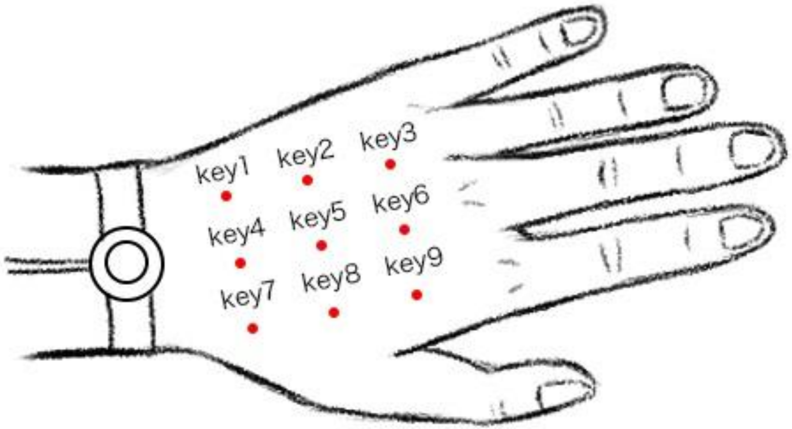
92.3%



87.5%

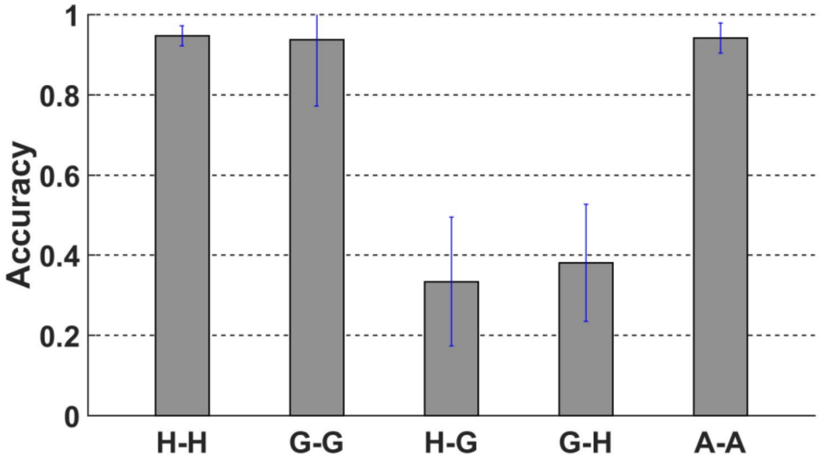
Experiments were conducted with 8 subjects.
We choose opisthenar finally due to user preference.

Robustness——Location setting



Experiments were conducted with 8 subjects.
We choose opisthenar finally due to user preference.

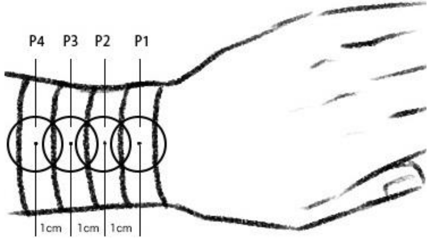
Robustness——Tap Strength



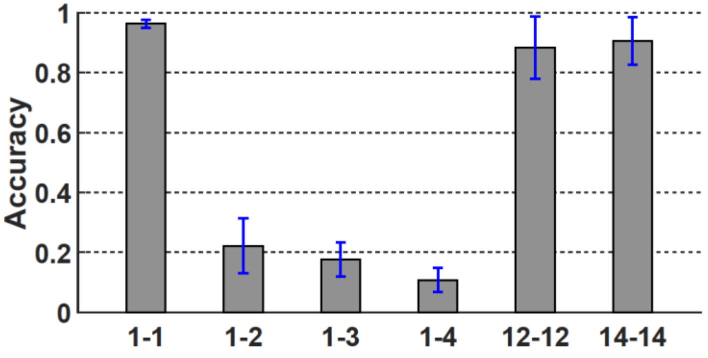
Hard - Gentle - All

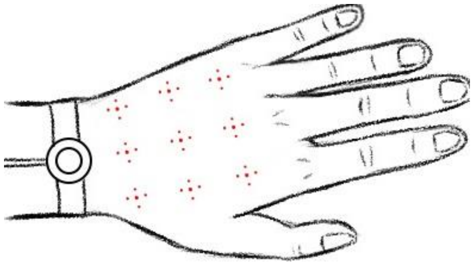
- Different tap force leads to lower classification accuracy.
- The accuracy recovers to “all-all” situation.

Robustness——Displacement

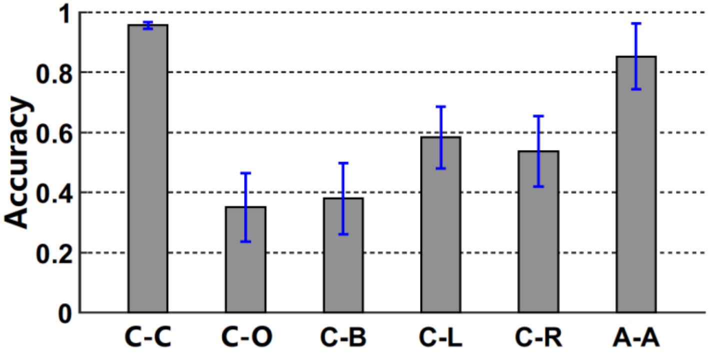


Sensor Displacement





Tap Displacement



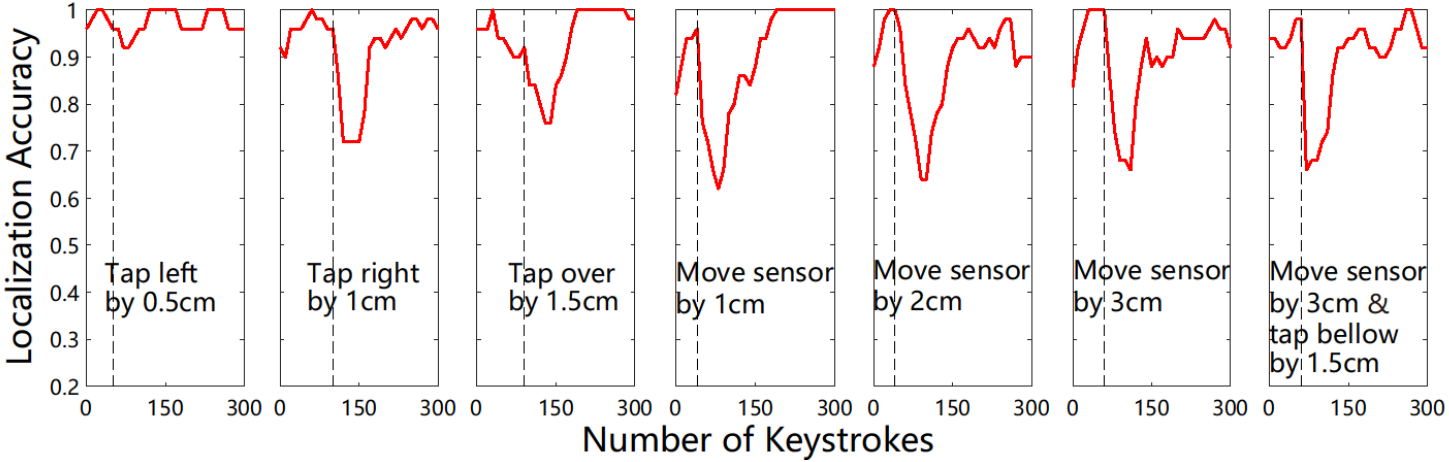
Center - Over - Below - Left - Right - All

X-axis format:
"training data" – " test data"

The system's performance suffers a degradation under displacement impact

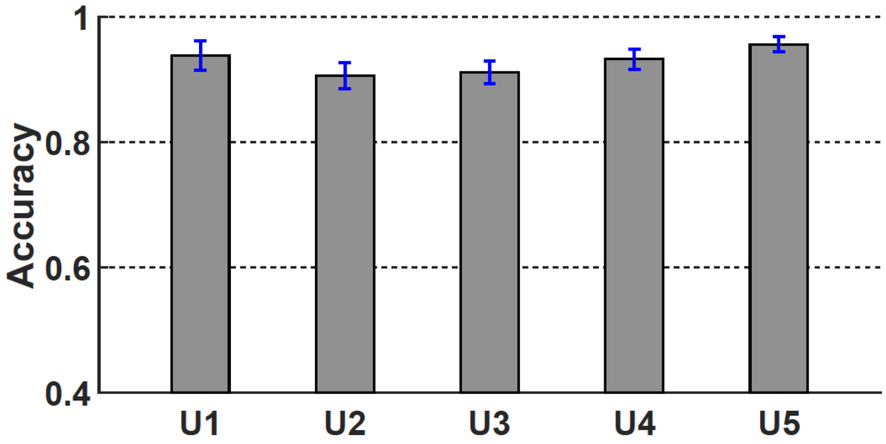
Runtime Adaptation

Robustness——Calibration & Adaptation



The calibration and adaptation scheme mitigate the displacement impact, and it can recover the accuracy to above 95% after a few tens of inputs

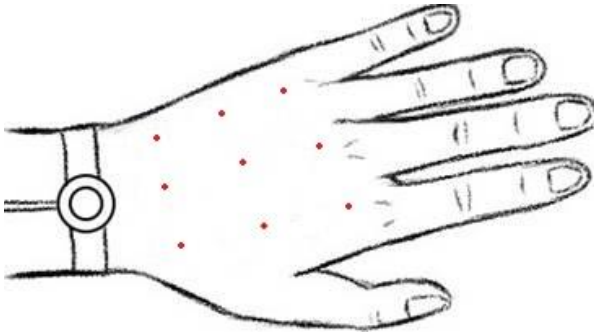
Robustness——Mobility



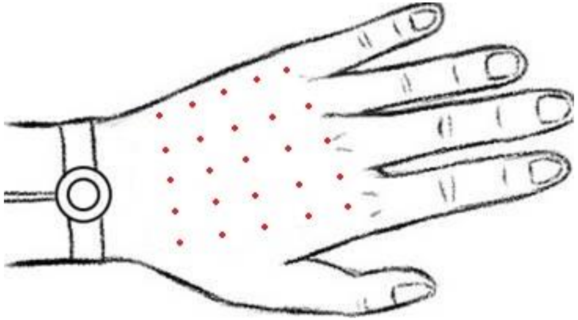
The average accuracy is **92.8%**, which is showing the robustness to human mobility

The noise caused by human mobility is at low frequency (less than 10Hz)
We remove it via a 20Hz Butterworth high pass filter

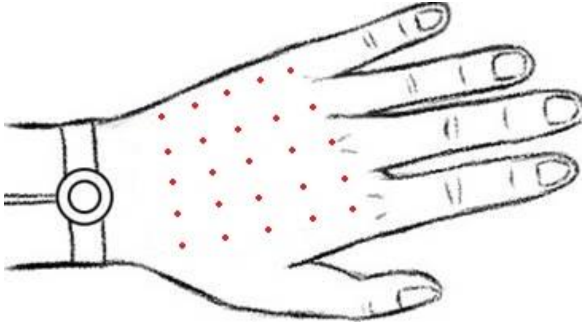
Robustness——Layout Extension



3*3 Layout: 95.7 %



4*4 Layout: 92.6%



5*5 Layout: 89.2%

Evaluation

1

Accuracy

2

Robustness

3

User Study

Evaluation

1

Accuracy

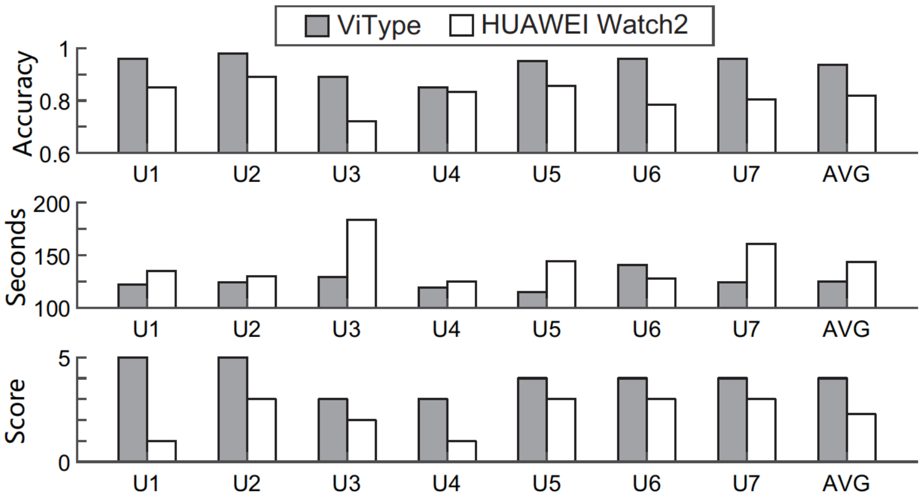
2

Robustness

3

User Study

User Study

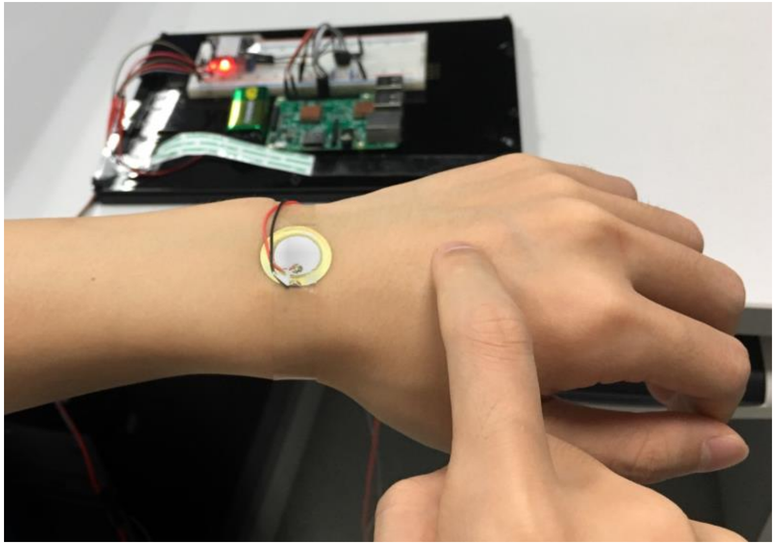


Items	Vitype	HUAWEI Watch2
Accuracy	93.6%	81.9%
Input Speed(s)	124.8	161
Score(0-5)	4	2.3
tightness (1=loose, 5=tight)	Comfort (1=uncomfortable, 5=comfortable)	Training accept
2.4	4.4	positive

ViType, as a typing system with larger interaction interface,
does provide higher input accuracy, faster input speed, and better user experience.

Cost

- Initial training: 3 minutes
- Training duration: 0.6 seconds
- Latency : 0.2 seconds
- Sensor: 0.15 dollars.



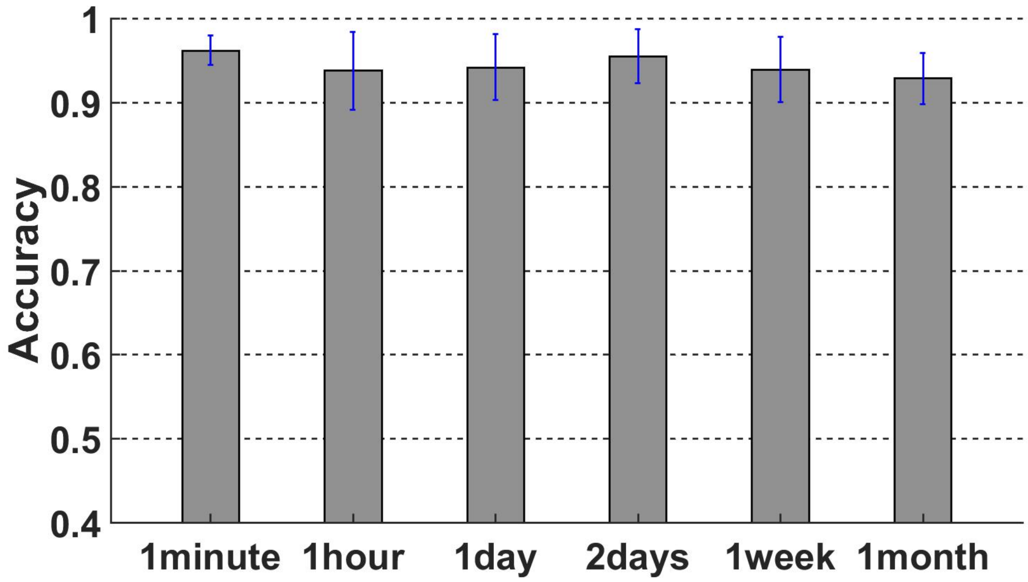
Demonstration of ViType

Conclusion

- ViType firstly turns hand back into virtual keyboard with **only one vibration sensor.**
- Our systems achieve up to **1.5X improvement** in classification accuracy sampling at **600Hz.**
- We evaluate the accuracy and robustness under different common conditions and design the calibration scheme to improve the **robustness**.
- ViType outperforms the input method in COTS smart watch.

Thank you!

Robustness——Temporal stability



The classification accuracy has no significant change over a month

$$PSD = 10\log_{10}\frac{abs(FFT(k_i))^2}{f_s \times n}$$

f_s: sampling rate

k_i: received signal

n: the number of samples of k_i

$$x' = \frac{x - \min(x)}{\max(x) - \min(x)}$$

x: raw data