VibWriter: Handwriting Recognition System based on Vibration Signal

Dian Ding, Lanqing Yang, Yi-Chao Chen, Guangtao Xue

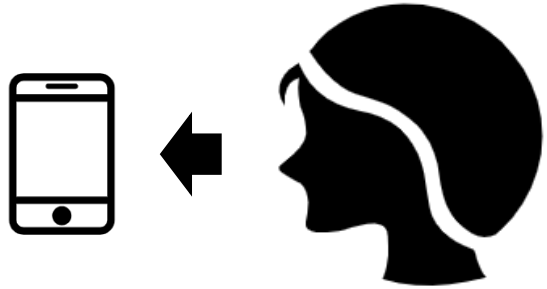
Shanghai Jiao Tong University

Outline

- Background and Motivation
- Preliminary
- System
- Evaluation
- Conclusion and Future Work

Background

Smart phones are indispensable …



Efficient interaction is **IMPORTANT**!

HCI based on handwriting recognition

- Localization-based methods

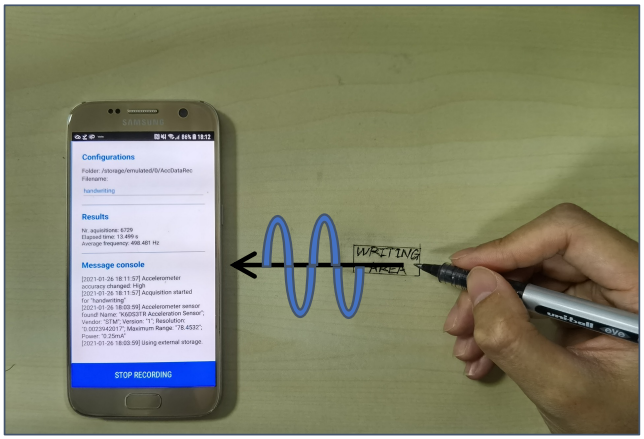
External hardware is required!

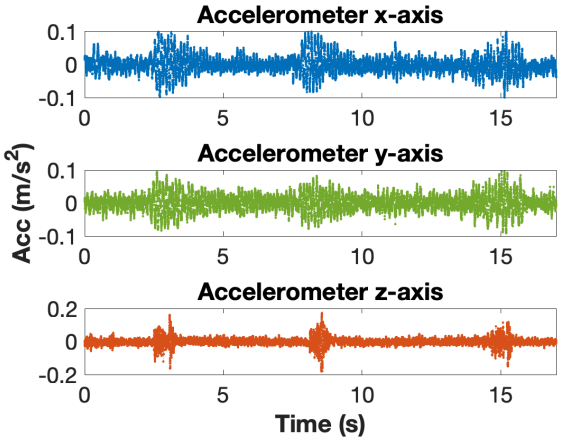
- Scratch-based methods

Sensitive to ambient noise!

Vibration based handwriting recognition

- **Common phenomenon:** Vibration signal of handwriting propagates on the desk.

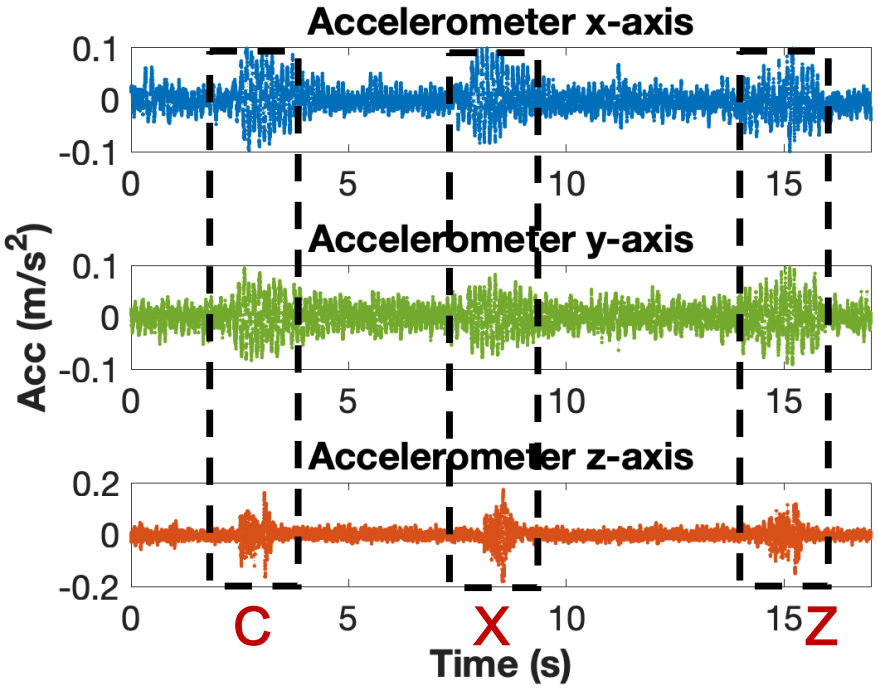




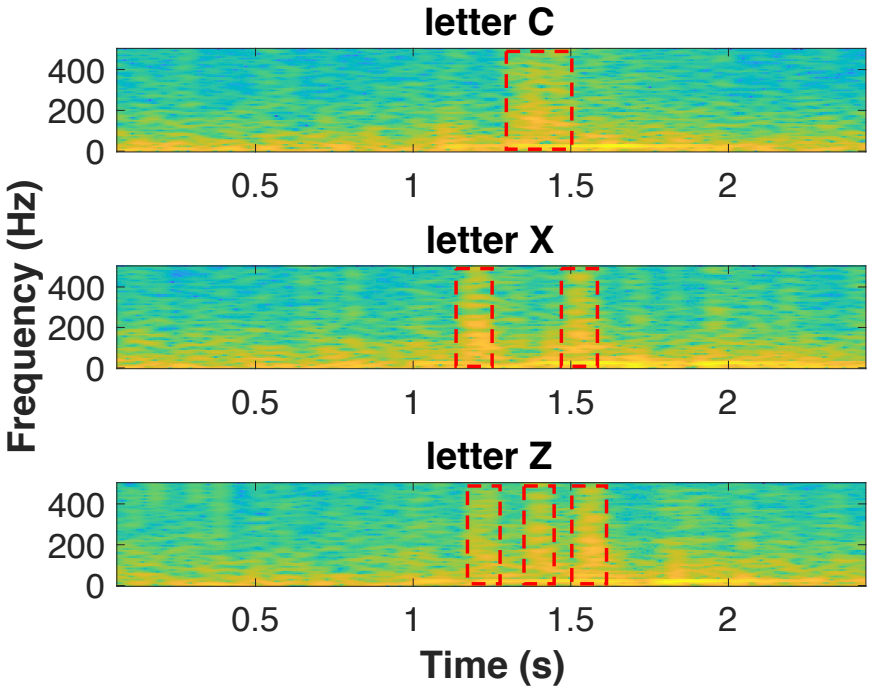
- We propose ***VibWriter***, a novel vibration based system using ***accelerater***
- Advantages of ***Vibration signal***:
  - Contain enough information for handwriting recognition
  - Data accessibility, and robust to noise

Preliminary

- **Q1:** Vibration signals of different letters.



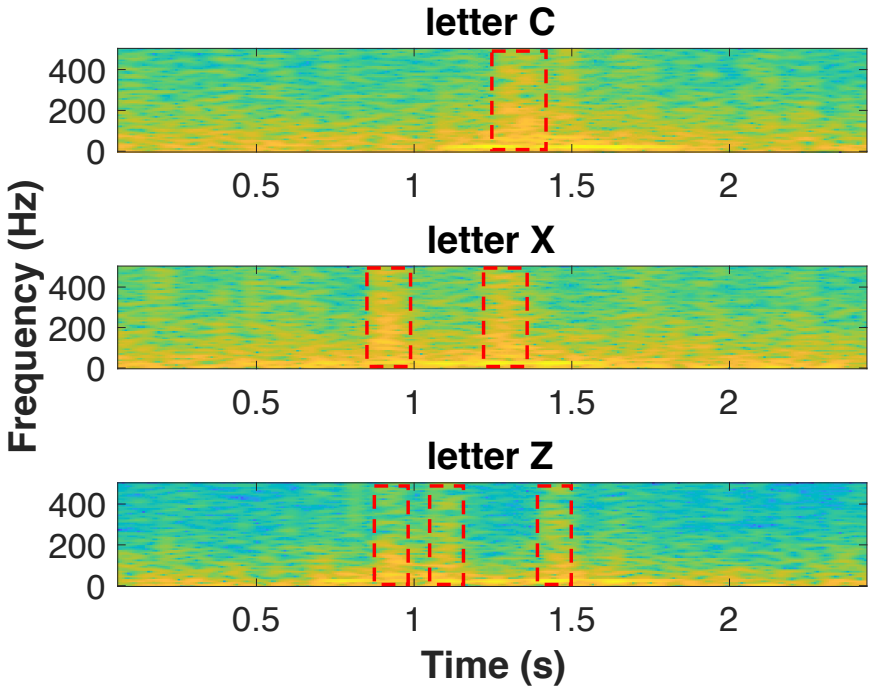
- Vibration signal in time domain



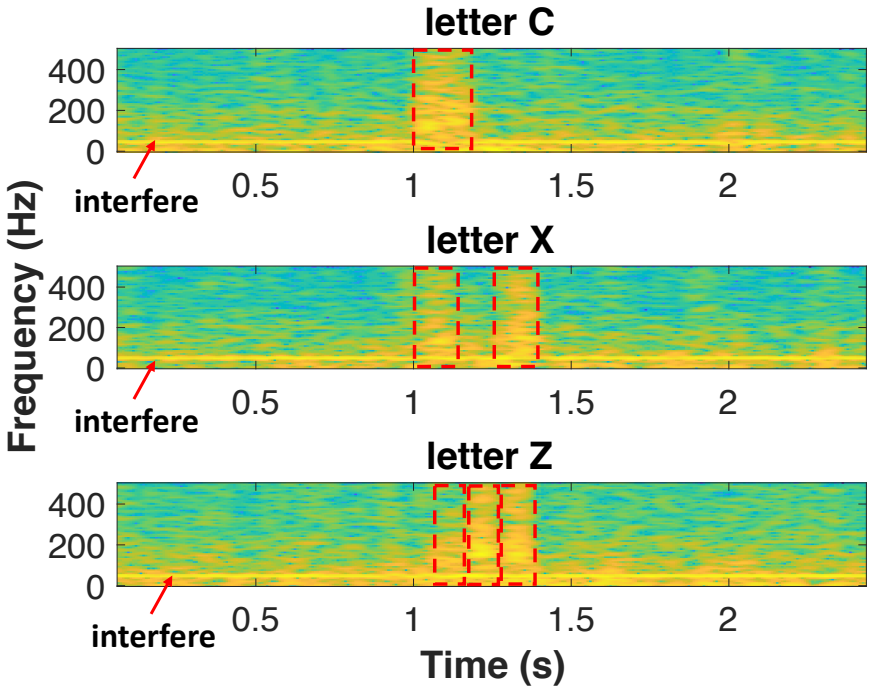
- Vibration signal in frequency domain

Preliminary

- **Q2:** Vibration signal of different users and conditions.

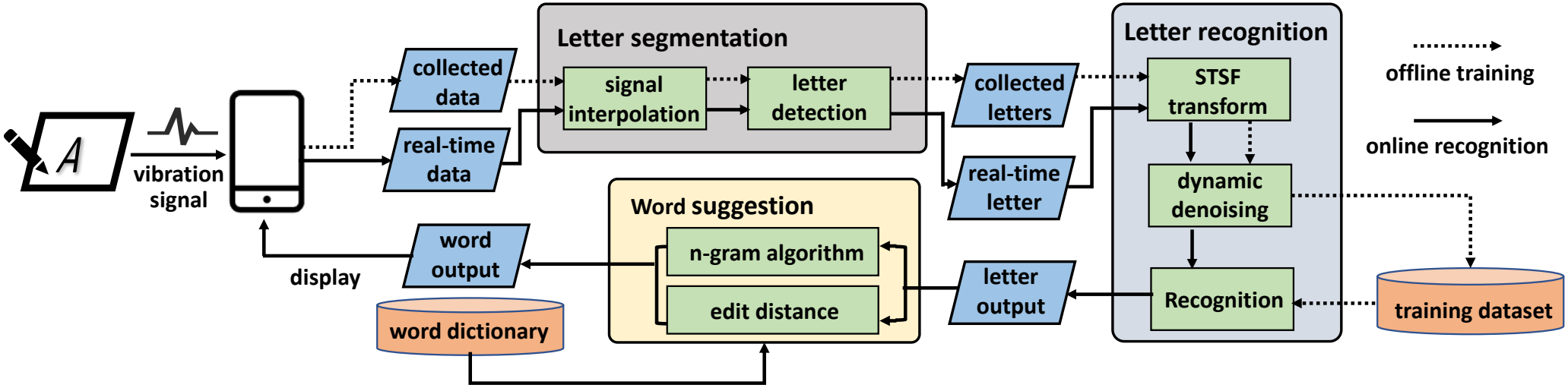


- Vibration signal of user 2

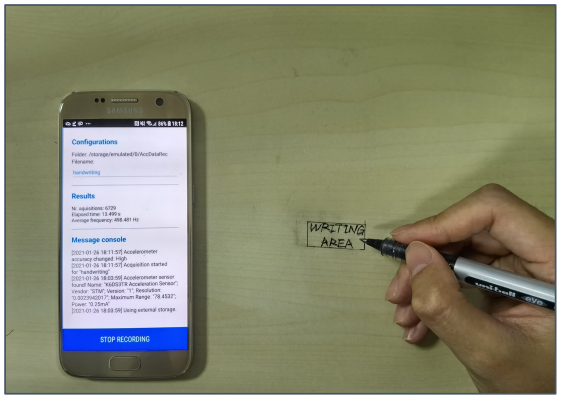


- Vibration signal with interferes

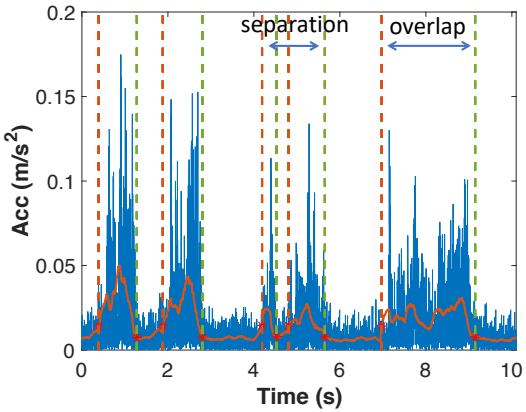
System Workflow



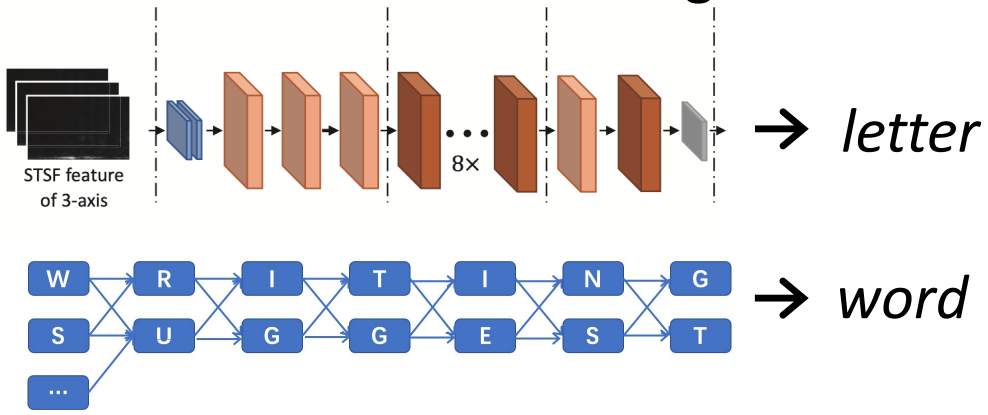
- Vibration signal



- Letter segmentation

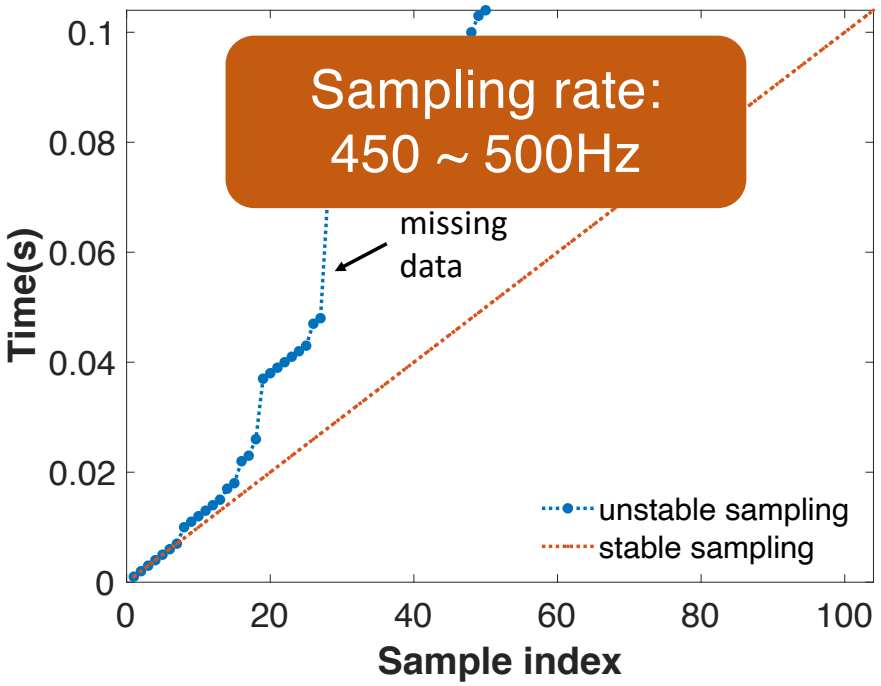


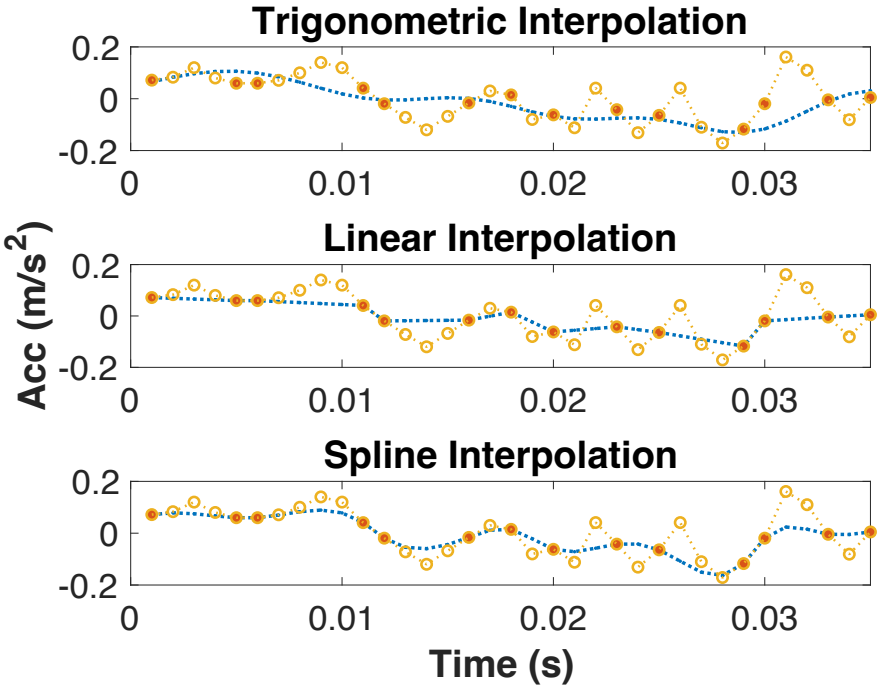
- Letter and word recognition



System - *Letter Segmentation*

- ***Unstable sampling*** at high sampling rates.

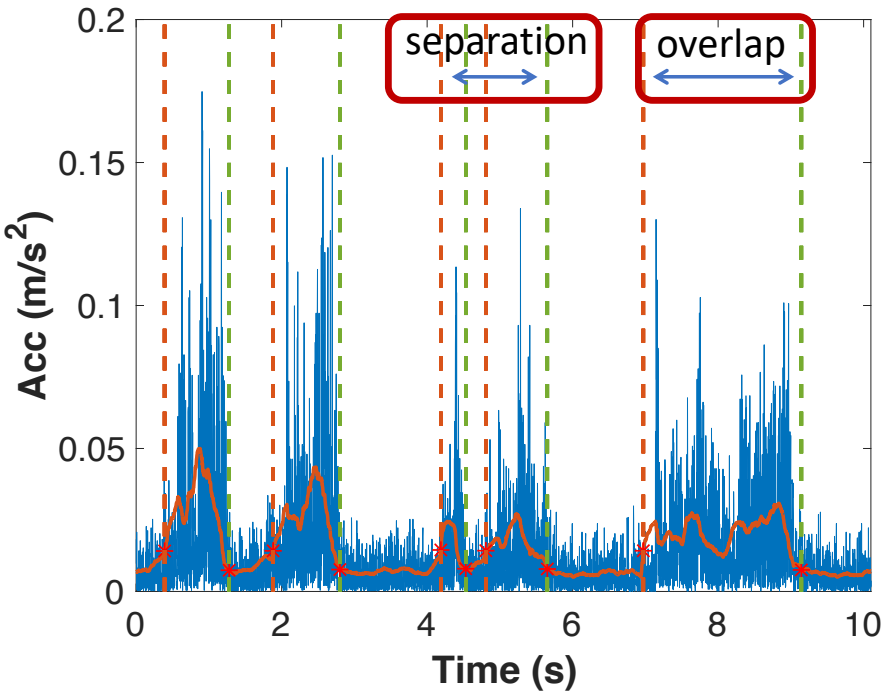




- Missing samples in the time domain
- Comparison of interpolation algorithms

System - *Letter Segmentation*

- Amplitude based ***letter segmentation***



- Vibration signal with sliding window

$$S(t)_{mean} = mean[S(t - t_w, t + t_w)]$$

Letter start: $0.2 \times max + 0.8 \times min$

Letter end: $0.1 \times max + 0.9 \times min$

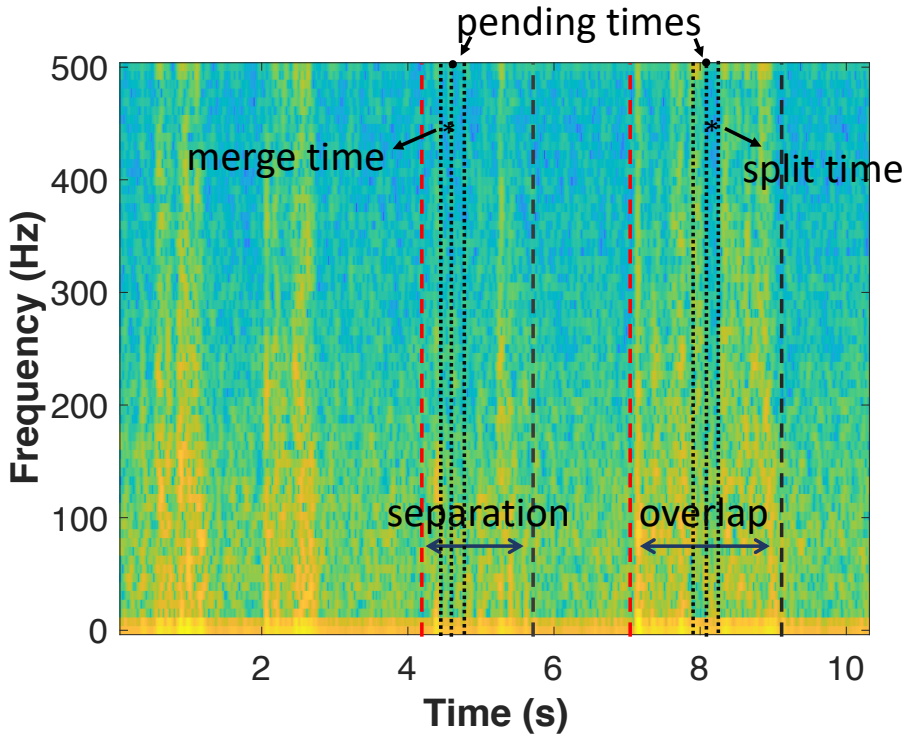
- Segmentation errors

Interruption → ***Signal separation***

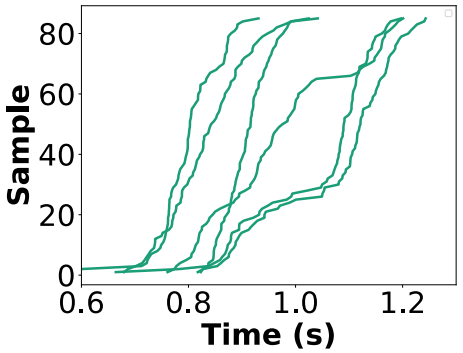
Continuous writing → ***Signal overlap***

System - *Letter Segmentation*

- Spectrum-based ***segmentation optimization***



- **High-frequency components associated with strokes**
- Detection of the segmentation errors



Shorter than 0.6s*:*

signal separation

Longer than 1.2s *:*

signal overlap

System - *Letter Recognition*

- Preprocess: ***signal spectrum*** and ***signal denoising***

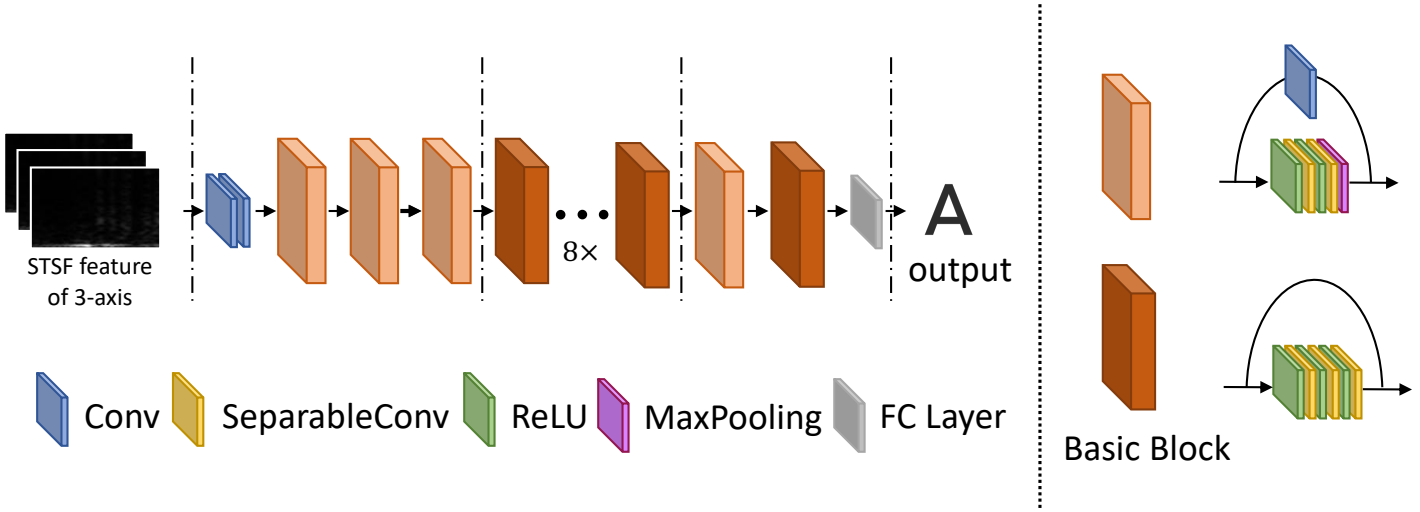
  STFT (Short Time Fourier Transform)

$$STFT\{x[t]\}(m,\omega) \equiv X(m,\omega) = \sum_{n=-\infty}^{+\infty} x[n]\omega[n-m]e^{-j\omega n}$$

  Spectrum Subtraction

$$\|Y(k)\|^2 = \|S_{signal}(k)\|^2 - \|\hat{S}_{noise}(k)\|^2$$

- Classification: ***Xception*** with ***Focal Loss***



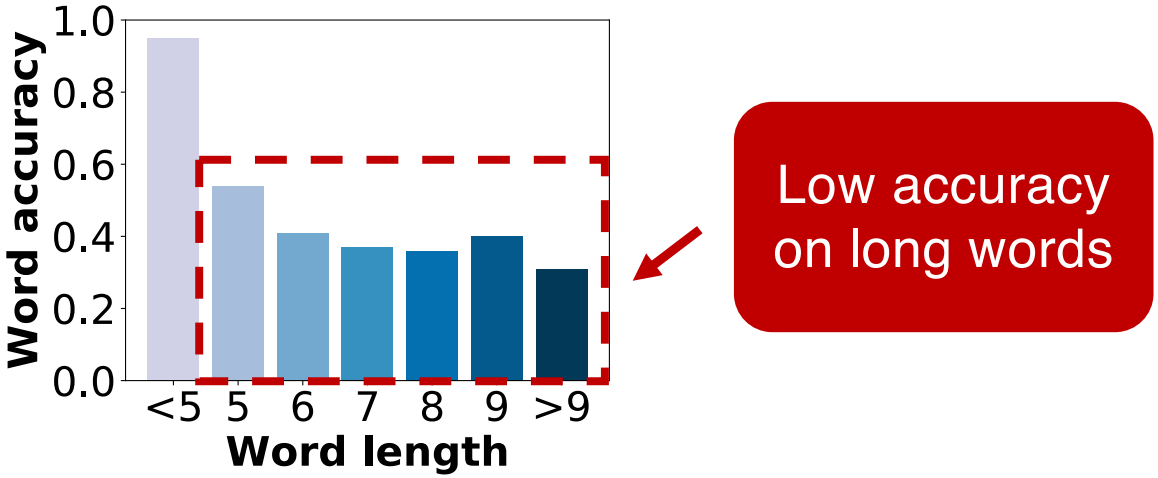
System – *Word Suggestion*

- ***N-gram algorithm*** based word suggestion

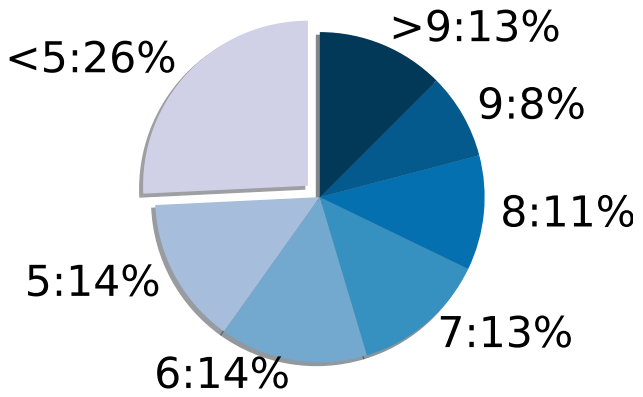
$$P(\omega_1, \omega_2, ..., \omega_n) = P(\omega_1)P(\omega_2|\omega_1)\cdots P(\omega_n|\omega_1, ..., \omega_{n-1})$$

$$P(\omega_i|\omega_1, ..., \omega_n) = \prod_{i=1}^{n} P(\omega_i|\omega_{i-1}, \omega_{i-2})$$

- **Accuracy** of word suggestion



- **Word distribution** of COCA



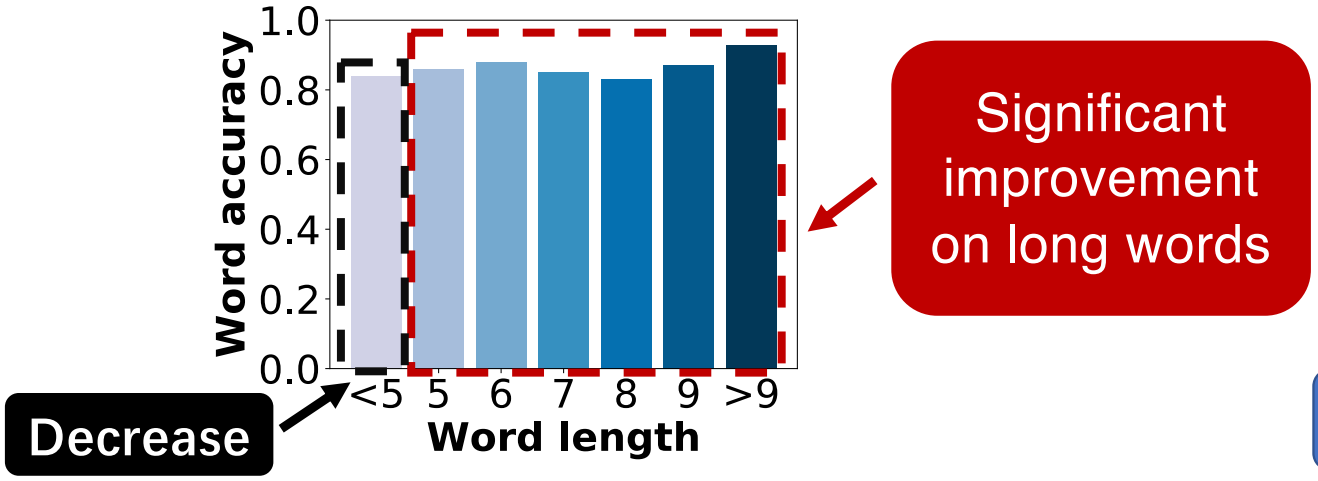
System – *Word Suggestion*

- ***Edit distance*** based word suggestion

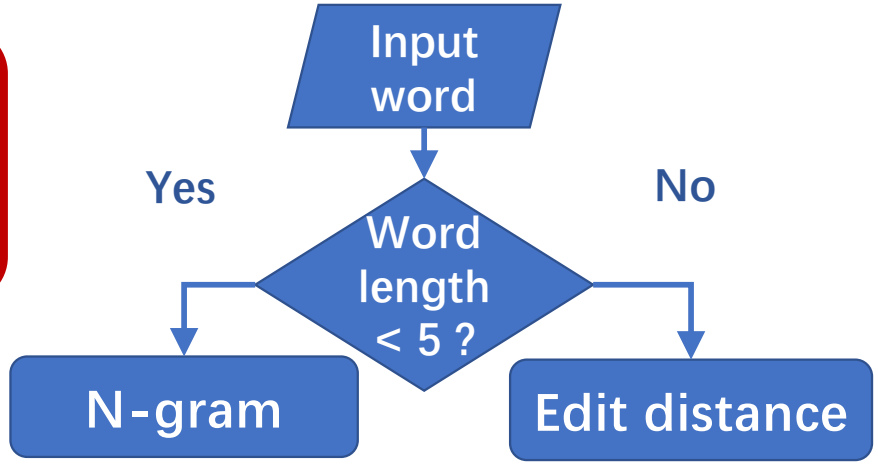
i \ j		0	1	2	3	4	5	6	7	8
		ϵ	C	A	T	G	A	C	T	G
0	ϵ	0	0	0	0	0	0	0	0	0
1	T	1	1	1	0	1	1	1	0	1
2	A	2	2	1	1	1	1	2	1	1
3	C	3	2	2	2	2	2	1	2	2
4	T	4	3	3	2	3	3	2	1	2
5	G	5	4	4	3	2	3	3	2	1

Permitted editing operations:
Replacing one character,
inserting one character,
deleting one character

- **Accuracy** of word suggestion



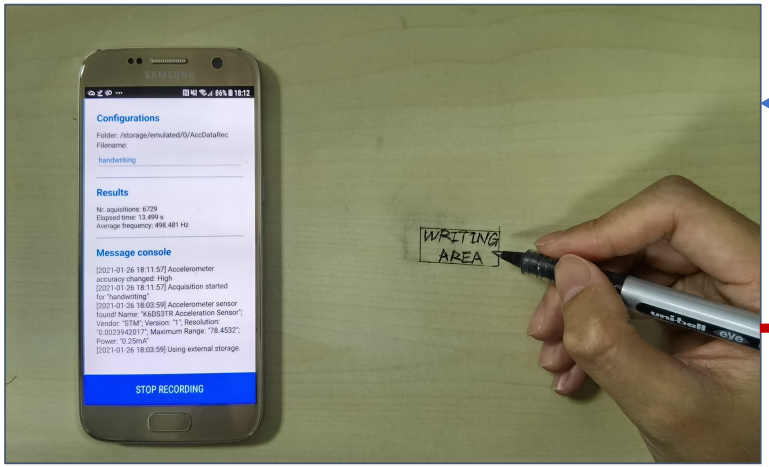
- Word suggestion system



System – *Prototype*

Handwriting on the desk → Segmentation of vibration signal → Letter recognition and word suggestion → **Vibration based handwriting recognition**

- **Mobile Input**
- **Server**

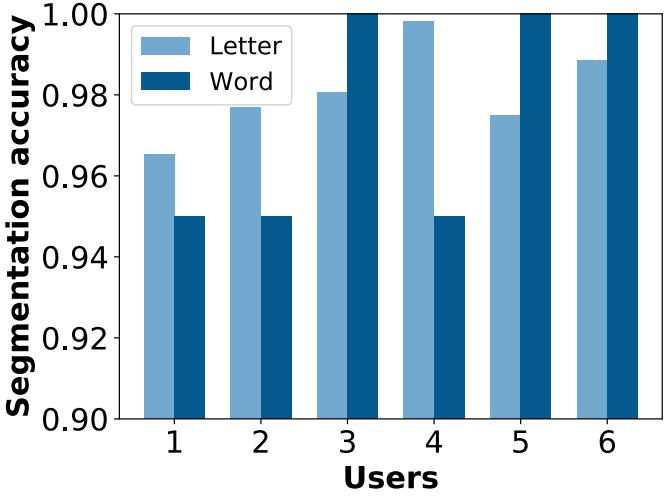


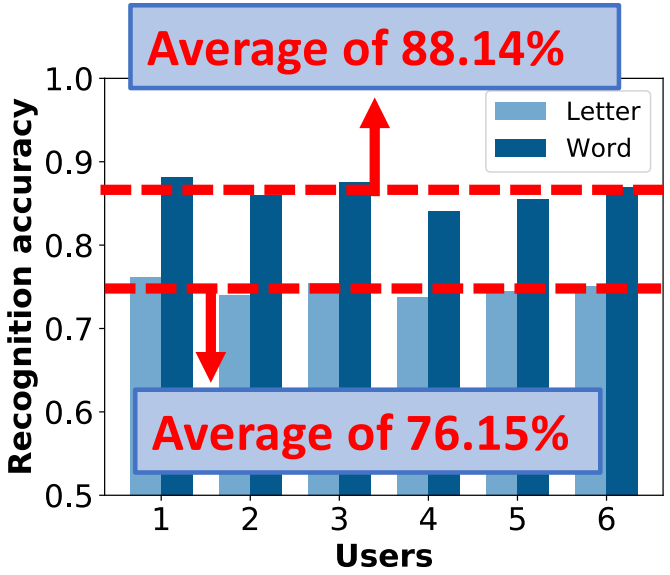
Recognition Result

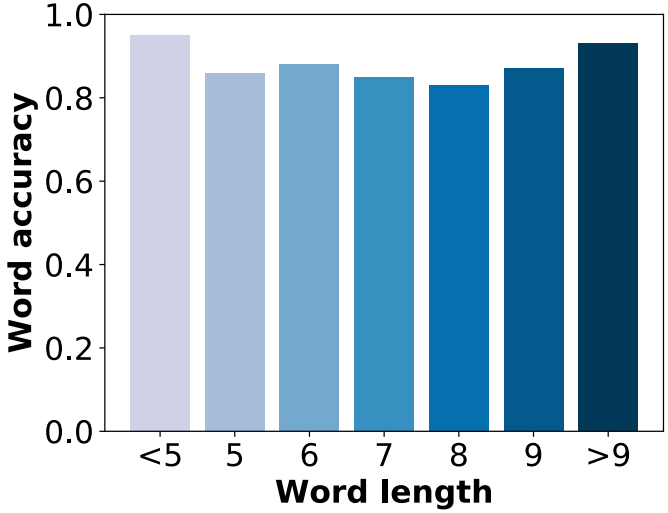
Vibration Signal

Evaluation

- Micro benchmarks

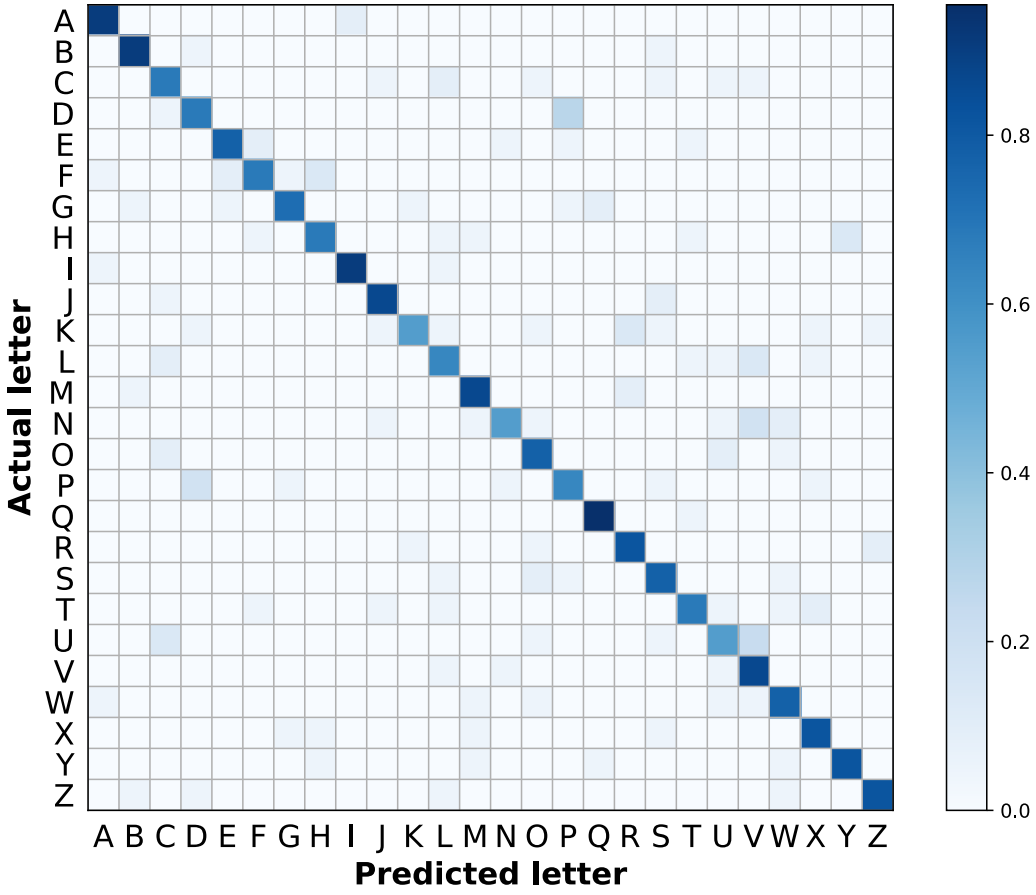




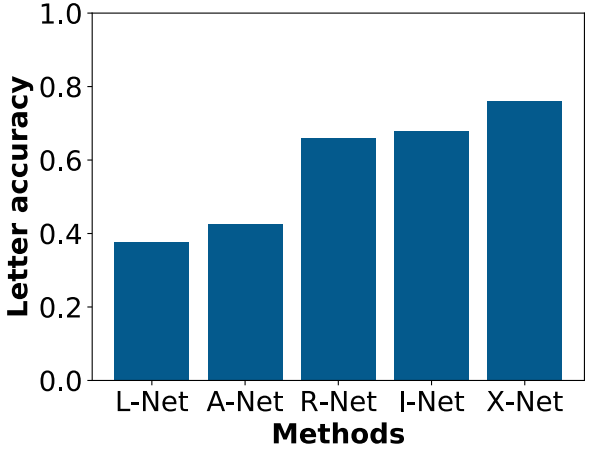


- **Signal segmentation** accuracy of different users
- **Letter and word recognition** accuracy of different users
- **Word suggestion** accuracy of different lengths

Evaluation



- **Letter accuracy**



- **Accuracy** of different methods

TABLE I
USER SATISFACTION OF *VibWriter*.

Satisfaction	Accuracy	Speed	Delay	Security
Very Satisfied	8	7	5	10
Satisfied	9	11	10	8
Normal	3	2	5	2
Unsatisfied	0	0	0	0
Very Unsatisfied	0	0	0	0

- **User Study** of ***VibWriter***

Conclusion and Feature Work

Conclusion

- Feasibility of a smartphone's built-in accelerometer to perceive the handwriting vibrations on the desk
- Signal processing techniques required to recognize handwriting vibration signals

Future work

- Expansion of handwriting input applications: numbers, symbols, etc.
- Recognition accuracy and timeliness improvement: multi-sensor fusion, model compression, etc.

Thank you !