EchoWrite: An Acoustic-based Finger Input System Without Training

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Outline

01  Motivation
02  Related Work
03  System Design
04  Evaluation
05  Conclusion
Motivation

PC Era  2000  Mobile Era  2020  IoT Era

1980
Motivation

Traditional interaction interface - **Keyboard**

- Smartphone
- Table computer
- PC
Motivation

For new smart devices? Small screen size / no screen!

Smart watch  Smart glass  Smart home
Hand gesture recognition

Coarse-grained HAND gesture

Acoustic finger tracking

Two microphones are required

7. Y. Zou, Q. Yang, Y. Han, D. Wang, J. Cao, and K. Wu, “Acoudigits: Enabling users to input digits in the air,” in IEEE PerCom, 2019
### Related work

<table>
<thead>
<tr>
<th></th>
<th>Device</th>
<th>Device-free</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Training</strong></td>
<td>[3] [4]</td>
<td>[7]</td>
</tr>
<tr>
<td><strong>Training-free</strong></td>
<td>[1] [2]</td>
<td>Coarse-gained</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Two mics</td>
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<tr>
<td></td>
<td></td>
<td>One mics</td>
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</table>

*EchoWrite*
Principle: Doppler Effect

Frequency of a sound wave changes as a listener moves toward or away from the source
Six basic strokes of English letters*

horizontal  vertical  left-falling  right-falling  Left-arc  Right-arc

*“Using Mobile Phones to Write in Air”, Sandip Agrawal, et.al, ACM MobiSys, 2011
System Design - framework

Data collection

Preprocessing

Stroke recognition

Text recognition
1. How to recognize *finger* gestures in a *training-free* way?

2. How to input *continuously* under ambient *interference*?

3. How to *input text efficiently* based on *finger gestures*?
C1. How to recognize finger gestures in a training-free way?

Noise elimination
• Random noise: median filter
• Direct path: spectrum subtraction

STFT
C1. How to recognize finger gestures in a training-free way?

**Stroke profile extraction**
- Normalization + Binarization
- Image processing: *Area open, flood fill*
- Profile extraction: Mean Value-based Contour Extraction (MVCE) algorithm

**Stroke profile**
C1. How to recognize finger gestures in a training-free way?

Strokes Recognition

- Template matching
- Dynamic time wrapping (DTW)
C2. How to input continuously under ambient interference?

**Successive Strokes Segmentation:**

- Traditional methods: based on speed (i.e. Doppler frequency)
- **Key observation:** In the end of stroke writing, the speed remains but acceleration decreases notably.
- Acceleration can be utilized to discriminate strokes and other movement (arm, body, and other objects)
C2. How to input continuously under ambient interference?

Successive Strokes Segmentation
- Acceleration: first-order difference
- Green box: moving objects
- Green circle: Uninterrupted writing

\[
f_t = \frac{1 \pm \frac{v_f}{v_s}}{1 \mp \frac{v_f}{v_s}} f_0 = \pm \frac{2f_0 v_f}{v_s + v_f} + f_0 \approx \pm \frac{2f_0 v_f}{v_s} + f_0
\]

\[
f'_t = \frac{2f_0}{v_s} v'_f - \frac{2f_0}{v_s} a
\]
C3. How to input text efficiently based on finger gestures?

Referring to T9 Keyboard

- Each stroke represents several letters (started by this stroke when writing).
- Users can customize their own writing habits.
C3. How to input text efficiently based on finger gestures?

Example: Input ’TO’

I, T, Z, J

C, G, O, Q

IC
IG
IO
IQ
TC
TO
TQ
...

NAÏVE!
C3. How to input text efficiently based on finger gestures?

Bayesian-based Linguistic Model
• Tolerating possible errors (recognition or writing)
• Auto-associating the next possible word.

Pre-coding

Corpus (COCA)

Dictionary
{word, frequency, length, strokeSequence}

Stroke sequence (I)

arg max
  P(W | I)

W: word
I: Input

2-gram data

Word association
### Evaluation - setup

<table>
<thead>
<tr>
<th>Meeting room</th>
<th>Lab area</th>
<th>Entertainment zone</th>
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</table>

3(sessions) × 6(participants) × 6(strokes) × 30(repetitions) = **3240 strokes**

6(participants) × 10(words) × 20(repetitions) = **1200 words**

Huawei watch 2 vs Huawei mate 9
Evaluation – stroke recognition

Different devices
• Smartwatch: 94.4%, Smartphone: 94.7%

Different environment
• 94.4%, 94.9% and 93.2% in meeting room, lab area and entertainment zone.

Different participants
• 95.6%, 93.5%, 93.1%, 93.0%, 94.8% and 95%, respectively.
• The standard deviation is about 1.1%.
Evaluation – word recognition

**Different words**
- Average top k accuracies over different words are 73.2%, 85.4%, 94.9%, 95.1% and 95.7%.
- Providing three candidates, the inferring accuracy is up to 94.9%.

**Linguistic model**
- The average accuracies are 84.5% and 88.9%, for cases with and without Linguistic model.
**Evaluation – input speed**

**WPM: Words Per Min   LPM: Letters Per Min**

**Speed of text-entry**

- The average texts-entry speeds over all participants with *EchoWrite* and smartwatch keyboard are 7.5 WPM and 5.5 WPM, respectively.
Evaluation - User experience

User experience assessment
- Performance, Frustration and temporal demand are the top 3 factors that affect users’ assessment on a text-input system.
- the overall score of participants shows, smartwatch soft keyboard has higher workload than EchoWrite.

NASA-TLX workload factors:
- mental demand (MD)
- physical demand (PD)
- temporal demand (TD)
- performance(Pe)
- effort (Ef)
- frustration (Fr)
EchoWrite – conclusion

We design and implement EchoWrite which can recognize fine-grained finger-writing strokes without training.

With high-frequency signals and careful-designed processing pipeline, EchoWrite is robust to ambient noise and moving interference.

EchoWrite enables users to perform text-entry in the air with the speed of 7.5 WPM with the commodity microphone and speaker.
THANKS

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