Implementation and Evaluation of Document Retrieval for the PC Notes Taker (PCNT) Handwriting Device

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November 1, 2007
Outline

- Introduction
- Method
- Testing and Evaluation
- Results and Discussions
- Summary
Handwriting

- **Handwriting** is used for
  - literary writing
  - correspondence
  - advertisement
  - ...

- its **electronic articulation** are
  - typewriter
  - computer

- hasn’t lost **importance** due to claims of
  1. authenticity
  2. (inter-)mediality
  3. coporeality
Digital Handwriting

- Digital representation of the information of a user’s handwriting
- A way to convert written words from the ink on paper to digital format

**Acquisition Approaches**

1. **Offline** handwriting acquisition
2. **Online** handwriting acquisition
Offline Handwriting Acquisition

- Visual representation of a text
- No dynamic information
- A scanned image of handwriting is digitally read in

Applications
- Optical Character Recognition (OCR)
- Intelligent Character Recognition (ICR)

Disadvantages
- Noise from scanning the text
- Lines or patterns
- Extra marks due to dust or scratches
Online Handwriting Acquisition

- The way a text is written is important
- **Digital ink signal:**
  - a sequence of 2D points over time
  - information of strokes & trajectories
- **Devices** to capture digital ink
  1. digital pen on a patterned paper
  2. paper-based capture device
  3. pen-sensitive surface (touch screen)
- **Advantages**
  - No optical noise, easier data processing
  - Broad range of applications

Image by visoinobjects
Document Retrieval

Given a set $D$ of documents and a query word $q$, find a list $D'$ of documents where $q$ occurs at least once

$$D = \{d_1, d_2, d_3, ..., d_n\}$$
$$D' = \{d'_1, d'_2, d'_3, ..., d'_n\}$$

query $q$ and documents $D$ are handwritten

Document Retrieval Methods

1. Textual recognition
   - most intuitive, simple string search on textual features
   - fails in most searches, not suitable for hand-drawn images

2. Direct handwriting matching
   - works for all kinds of scripts and images
   - our method lives under this category
Aim of the Work

- **Part A:**
  1. Introduction of sub-features used for document retrieval
  2. Comparison of existing and newly introduced features

- **Part B:**
  1. Implementation of document retrieval system for PC Notes Taker (PCNT) device
  2. Evaluation of our method against PCNT and its comparison with those already tested
Document Retrieval Algorithms

**Ideal Retrieval Algorithm**

1. low complexity
2. works with simple features
3. faster and accurate

**Existing Approaches**

- Image feature indexing (Srihari et al.)
- Pattern recognition & machine learning (Schomaker et al.)
- Graph matching approach (Fonseca et al.)
- **String matching** (Sun et al.)
String Algorithms - Approximate String Search

- How close two strings (query & its instance in document) are.
- **Edit distance**, most common similarity measure

**Approximate String Search - Local Alignment**
- fuzzy search of short string \( (q) \) within a longer one \( (d) \)
- a matrix \( D \) of dimension \((m + 1) \times (n + 1)\)
- \( m \) and \( n \) are length of \( q \) and \( d \)
- for a match \( D(m, j) < \tau \), \( \tau \) is a threshold

\[
D(i, j) = \begin{cases} 
0 & \text{if } i = 0, \\
D(i - 1, 0) + 1 & \text{if } i > 0 \text{ and } j = 0, \\
\min \left\{ \begin{array}{l}
D(i, j - 1) + 1 \\
D(i - 1, j) + 1 \\
D(i - 1, j - 1) + \delta(i, j)
\end{array} \right. & \text{else,}
\end{cases}
\]

\[
\delta(i, j) = \begin{cases} 
0 & \text{if } q[i] = d[j], \\
1 & \text{else,}
\end{cases}
\]
Handwriting Features

- Feature data represent ink traces of a writing process
- Approximate string search works with string features
- String features: $x_t, y_t$ position of pen tip over time $t$
- **Freeman grid codes** - string features
  - 1. discretization of data with a grid
  - 2. assignment of codes to discretized data
- **Square** Freeman grid codes
- **Triangular** Freeman grid codes
Square Freeman Grid Codes

- Two sets of evenly spaced lines perpendicular to each other - square grid
- Handwritten input is superimposed on the grid
- Sample points $x_t, y_t$ are mapped to nodes
- Each sample point gets one of 8 symbols
- 9th symbol to encode a gap
- Encoded ink shape is sequence of symbols rather than sample points $x_t, y_t$
Square Freeman Grid Codes

222445566677012240066
Three sets of lines at 60-degree angle to each other - **triangular grid**

Quantization and assignment of codes for feature extraction is similar to square grid type except

1. **Triangular grid** to superimpose handwriting onto
2. **Six node symbols** to map sample points
Triangular Freeman Grid Codes

$h = a \sin 60^\circ = \frac{1}{2} \sqrt{3} \ a$
Triangular Freeman Grid Codes

23344550011355
Freeman Codes

Freeman Codes

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Document Retrieval for PC Notes Taker
**Pegasus PC Notes Taker Device (PCNT)**

- **PCNT** captures handwriting online
- Its package comes with
  1. a cordless electronic pen
  2. a detachable base with USB cable
- For applications, its SDK is available to
  1. to capture data from device
  2. to process it accordingly
- Coverage area: A4 size paper
- Resolution: 1200 DPI
Data Collection

- No suitable testset database available

- Built our own database
  - in English and Urdu scripts
  - documents written with PCNT
  - documents read in with SDK

- Database
  - 80 documents by 8 persons
  - 5 documents per person in each script
  - documents contents - repetitive words/phrases
  - 29 queries manually selected & tagged
  - 804 true matches selected & tagged
Data Collection

Diagram:

- User
- PC Notes Taker Device (PCNT) Generated Data
- PCNT SDK
- Docmment
- Ink Documents
- Readable Documents
- Ground Truths
- Ground Truth Selection

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Document Retrieval for PC Notes Taker
Performance Measures

- Search operation results in
  - matches,
  - mismatches and
  - missed instances

- Retrieval measures:

  \[
  \text{Precision} = \frac{\text{matches}}{\text{matches} + \text{mismatches}}
  \]

  \[
  \text{Recall rate} = \frac{\text{matches}}{\text{matches} + \text{missings}}
  \]

  \[
  F_1 \text{ measure} = \frac{2 \times \text{precision} \times \text{recall}}{\text{precision} + \text{recall}}
  \]
Freeman Grid Codes

- **Square** Freeman codes
- **Triangular** Freeman codes
- **Square vs. Triangular** Freeman codes
- **Freeman codes:** PCNT vs. ioPen
Square Freeman Grid Codes

Graphs showing precision and recall rates for different widths.
Triangular Freeman Grid Codes

![Graphs showing precision and recall rates with different widths for triangular Freeman grid codes.](image_url)
Square Vs. Triangular Grid Codes

- Freeman Grid Codes
- Square Freeman Grid Codes
- Triangular Freeman Grid Codes
- Performance with PC Notes Taker Device (PCNT)

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Document Retrieval for PC Notes Taker
### Performance with PC Notes Taker Device (PCNT)

<table>
<thead>
<tr>
<th>GS</th>
<th>PCNT Device</th>
<th></th>
<th></th>
<th></th>
<th>P</th>
<th>R</th>
<th>F₁</th>
<th>T</th>
<th></th>
<th>P</th>
<th>R</th>
<th>F₁</th>
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</table>

GS = Grid size, P = Precision (%)
R = Recall rate (%), T = Time (milliseconds)
Summary

- **Retrieval System**
  - Approximate string search - retrieval algorithm
  - It works with all kinds of scripts/figures

- **Handwriting Features**
  - **Freeman** to convert handwriting signals to code string
  - Introduced **triangular** Freeman features: 6 **equidistant directions** rather than 8 **directions** of **square** Freeman features
  - Little performance difference with both types of features

- **PC Notes Taker**
  - To build database, documents written in Urdu & English
  - benchmark: using triangular and square Freeman features
  - No performance difference from earlier tests with **ioPen**