Abstract

This paper describes a search method for unconstrained digital ink text and an application that searches for a
given keyword from accumulated digital ink text in a server. A considerable amount of research and development
has been made in hardware and software to promote pen interfaces. Therefore, we could expect digital ink data will
be accumulated in personal computers and network servers. We propose a search method for unconstrained digital
ink text and report a Digital Note Searcher employing the search method.

1 Introduction

Handwriting (pen input) is effective to write down one’s idea and stimulate one’s creativity. Human beings have
been producing new thought by writing down their ideas and developing them. Even in the today’s offices where
Information Technology (IT) is employed in many ways, most essential and intrinsic information is produced by
writing with a pen while a computer equipped with a keyboard and a mouse is used to browse, select and process
information. It is not so difficult for us to produce information and type it directly into a computer if it is just text but
it is not easy to produce information mixed with figures and formulas while working on a computer. We would have
to work on multiple software tools at the same time and pay attentions to their operations rather than just to thinking.
It would be clear that this is not the environment for us to foster our thinking. We only have to imagine solving math
on a computer with a keyboard and a mouse. By comparison, pen input is apt to cultivate our thoughts without being
bothered by operations to use a computer and software [1].

Pen interfaces started to spread from mobile systems where a keyboard or a mouse is hard to be employed. Now,
pen interfaces are being improved in both hardware and software. Recently, a computer system with LCD-integrated
tablet called tablet PC is being strongly promoted by a giant software company. Moreover, a new type of pen
interfaces on real paper are invented such as PC Notes Taker, Anoto Pen, DigiMemo and so on. They allow people
to write on real paper while retrieving and keeping time-sequence information of pen-tip coordinates from pen-down
to pen-up called digital ink. They will all provide handwriting with IT-empowered features and have the possibility
to support our creativity by handwriting, although Tablet PC is more interactive while the latter group is less.

As these handwriting input interfaces are getting into our lives, it can be thought that digital ink data will be
accumulated into each computer or network servers in the future. Therefore, search functions will be the key to make
handwriting input interfaces more valuable for us as search engines to get desirable information out of enormous
data are the key factor to make World Wide Web so indispensable for us. This paper presents a searching method for
unconstrained digital ink text and an application that searches digital ink notes.

2 Software design of Digital Note Searcher

We first present the application that searches for a given keyword from accumulated digital ink notes (digital
notes in short).

2.1 Overview

We call this application “Digital Note Searcher”. Digital Note Searcher accumulates handwritten notes written in
the form of digital ink text and provide the search function for them. We design it as a client server system. Its
configuration is shown in Fig. 1.
In general, a sophisticated character recognition method requires a considerable amount of computation time and memory. A low performance CPU such as that in PDA hardly satisfies users with the processing speed or the accuracy of recognition. In order to solve the issue, Sakurada et al. proposed a client server system that a low performance client sends digital ink data to a higher performance server and the server recognizes it and sends the result of recognition back to the client [2].

This client server architecture for digital ink recognition is good step for Digital Note Searcher. Digital ink notes can be accumulated into the server and they can be read not only from the device that collects digital ink notes, but also from any environment connected to the server though network. For example, from our home computer we may search for notes written on a PDA when we are away from our home. The hardware resource problem is also solved by the client server architecture since heavy computation can be made on the server.

2.2 Digital ink text search method

We propose a full-text search method for locating a keyword in digital ink text produced in free format without imposing any constraint of writing boxes, grids or baselines [4]. Here the problem is that the keyword may be presented from a keyboard as character codes while digital ink text is handwriting text patterns rather than a sequence of character codes.

Senda et al. proposed a search method for digital ink text by a keyword represented again in digital ink. In this case, pattern matching is the method for search [5]. This method does not need a character recognition engine and it is language independent but the search reliability may not be high enough. Search efficiency may also be degraded due to the pattern matching employed. Moreover, if the search keyword is input from a keyboard, its digital ink representation must be produced virtually and compared with digital ink text.

On the other hand, we consider a search method to digital ink recognition results that is a sequence of character codes by a keyword again represented as a sequence of character codes. In this case, we must assume that digital ink text is often mis-recognized (wrong answer is nominated as the top candidate although the correct answer may be within candidates). Incorrect recognition results would cause search losses. We propose a search method by a keyword with taking mis-recognition into account, which searches into the candidate lattice generated from candidates of recognition. The candidate lattice can be generated when digital ink text is saved in a database so that it does not incur its recognition time when the keyword is searched for. Since we search into the candidate lattice, we could reduce search losses by considering segmentation candidates and character recognition candidates.
2.3 Interface for collecting digital ink text

The client software collects digital ink notes. Collected digital ink notes are accumulated to the database server. In addition, by replacing the pen device driver, Digital Note Searcher corresponds to any pen device. Portable devices such as Anoto pen or PDA can be carried around as a notebook. USB devices such as PC Notes Taker could be used for deskwork.

2.4 Interface for searching digital ink text

When the users want to see their notes, they may do from any type of computer. Since our search method accepts the keyword as a sequence of character codes, it can be input straightforwardly from a keyboard. When the client to see the note is equipped with a pen rather than a keyboard, however, it must enable the users to write the keyword, send it to the recognition server, receive the recognition result, verify and correct the result and finally send the keyword in the form of a sequence of character codes to the server.

2.5 Implementation

We developed Digital Note Searcher, which collects digital notes from pen devices such as Anoto pen or Digi Memo (Fig.3) and searches collected digital notes using proposed unconstrained digital ink text search method (Fig 4). We employed our own recognition engine for unconstrained digital ink text [3].
Figure 3: Note taking on Digi Memo.

Figure 4: Digital note search application.
Fig. 4 shows a screen shot of the developed application where the left area is thumbnail images of note pages, the middle area is a selected page and the right area is search results. Web search engines sort search results in the appropriate order by their own criteria. Then, they show contents of searched web pages by displaying phrases including the searching keywords. Digital Note Searcher displays searched digital notes with highlighted keyword and surrounding area. This method is effective to display multiple searched notes in a limited and users can find a target note easily. By clicking on each searched note, they can enlarge it into the middle area.

3 Unconstrained digital ink text search method

This section describes the search method for unconstrained digital ink text and its evaluation.

3.1 Unconstrained digital ink text recognition

Generally, a recognition method for unconstrained digital ink text hypothetically segments digital ink text patterns into character pattern candidates to find possibly the optimal character candidate and segmentation candidate. Our recognition method picks up segmentation candidates and character recognition candidates with likelihood scores. These candidates are represented in a lattice structure where each node represents a character pattern candidate with possibly multiple character recognition candidates and each arc represents a segmentation candidate between a previous character pattern candidate and a succeeding character pattern candidate as shown in Fig. 5. We call it a candidate lattice. Then, the method finds an optimal text recognition result by using the Viterbi search.

![Figure 5: Candidate lattice.](image)

<table>
<thead>
<tr>
<th>Rank</th>
<th>Code</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>明</td>
<td>891</td>
</tr>
<tr>
<td>2nd</td>
<td>朋</td>
<td>873</td>
</tr>
<tr>
<td>3rd</td>
<td>門</td>
<td>860</td>
</tr>
</tbody>
</table>

![Figure 6: Recognition candidate.](image)

3.2 From recognition to search

Although the above recognition method tries to find the best interpretation by taking into account character recognition likelihood segmentation likelihood, context likelihood and so on, mis-recognition and mis-segmentation likely happen. If we just compare the keyword with the recognition result, it unlikely finds the keyword in the text of recognition result. Therefore, it is necessary to searches into the candidate lattice generated from candidates of recognition. This process also carried out by the Viterbi search. The candidate lattice is generated when digital ink text is saved in a database so that it does not incur its recognition time when the keyword is searched for. Since we
We could reduce search losses by considering segmentation candidates and character recognition candidates.

### 3.3 Setting optimal candidate pruning threshold

Among possible paths in a candidate lattice, only a single path is the correct answer and others are noises. Therefore, it is important for the search method into the candidate lattice to reduce the amount of search noises. We could reduce the amount of computation and search noises by pruning segmentation and character recognition candidates having low likelihood scores. We will use the term “candidate pruning threshold” to refer to a value of the border to prune.

We employed the database “TUAT Nakagawa Lab. HANDS-kuchibue_d97_06” (hereafter, we call it Kuchibue) for the experiment and evaluation of the search method. Kuchibue is a set of digital ink text written by 120 participants with each composed of 11,962 character patterns written by a single participant (10,152 character patterns in meaningful context, 1,810 character patterns without context) [6]. Participants wrote characters in a sequence of writing boxes one by one in each box on a LCD-integrated tablet. This is the style that we prepare text on manuscript papers. We employed the meaningful context part and made 120 virtually unconstrained digital ink text by throwing away the box information from digital ink text. Moreover, we use 1,000 kinds of search keywords for every length of two, three and four characters. We evaluate the search method by counting following measures:

\[
R = \frac{\text{The number of correct searches}}{\text{The number of keywords in the search target}} \tag{1}
\]

\[
P = \frac{\text{The number of correct searches}}{\text{The number of searched pieces of text}} \tag{2}
\]

\[
F = \frac{2}{1/R + 1/P} \tag{3}
\]

The recall rate defined in Equation 1 represents to what extent the keywords that should be searched in the target are really searched, while the precision rate in Equation 2 represents how much the searched items are correct. We evaluate the overall performance of the search method in terms of the \( F \) measure defined in Equation 3. We obtained an optimal candidate pruning threshold, which bring the highest \( F \) measure in each length of the keyword.

### 3.4 Results of Experiment

We obtained the results as shown in Fig.7 and Table 1.

![Figure 7: Relationship between recall rate and precision rate.](image)
Table 1: Experiment results.

<table>
<thead>
<tr>
<th>Length</th>
<th>Threshold by Score</th>
<th>Recall</th>
<th>Precision</th>
<th>F Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>820</td>
<td>83.3%</td>
<td>76.9%</td>
<td>0.799</td>
</tr>
<tr>
<td>3</td>
<td>771</td>
<td>88.7%</td>
<td>89.2%</td>
<td>0.890</td>
</tr>
<tr>
<td>4</td>
<td>687</td>
<td>89.5%</td>
<td>94.1%</td>
<td>0.917</td>
</tr>
</tbody>
</table>

Fig. 7 shows that there is a trade-off between the recall rate and the precision rate. Table 1 shows the optimal candidate pruning threshold, which brings the highest F-measure to each length of the keyword as well as its recall rate and its precision rate. The F-measure is higher than 0.75 for all the lengths of the keyword. We consider that these F-measures have practical accuracy. However, these results are just obtained by the experiment, so that search results might be irrelevant for different user demand. An amount of search results may be too little, or too large. A slider bar, which changes the threshold, might be useful so that users can control the recall and precision rates by themselves.

4 Future work

This section describes our future work.

4.1 A search method for documents, which mingle digital ink text and typed text

Our Digital Note Searcher only searches digital ink text. However, people take notes not only on white papers but also on printed papers. For example, people write in schedule books or address books, where “date”, “name”, “address” and “phone number” are originally printed. People take notes on documents, handouts. Moreover, they may fill in questionnaires. In these cases, digital ink notes make sense when related to printed contents. By the use of Anoto pen and Anoto paper, or Active Form System [7], computers can identify the document on which text has been written or is being written once the document is identified, we can obtain the character code sequence for the document. Then, there is no problem to apply the common searcher into the coded text as well as our search method for digital ink text so that we can search for a keyword into both handwritten text and originally printed text. For building this method, we also have to consider user interfaces for displaying search results from both the original text and digital ink text.
4.2 Writing direction free digital ink text search

The proposed digital ink text search method is only applicable to horizontal writing. We Japanese write text horizontally and vertically, however, and sometimes mix horizontal writing and vertical writing on a paper, or even write diagonally. Unfortunately, our current search method is not able to retrieve those notes.

To remove this limitation, we consider to employ writing direction free digital ink text recognition method to our present candidate lattice, which has recognition candidates and segmentation candidates. By adding writing direction candidates and also character orientation candidates to the lattice, our method should be able to search any digital ink text with any writing direction.

Removing writing direction limitation may incur different problems. The problems are the increased amount of computation and search noises, because the search space will be enlarged significantly. Then, to resolve these problems, we have to evaluate the likelihood of writing direction and character orientation candidates as well and set the optimal candidate pruning thresholds for writing direction and character orientation free text search.

5 Conclusion

This paper presented a searching method for unconstrained digital ink text and the application to search for a given keyword from accumulated digital ink text in a server. We evaluated the search method in terms of the recall rate, the precision rate and the $F$ measure. Next step is to seek for the best way to display search results through experiments from the viewpoint of user interfaces. Future work is to develop the search method for documents, which mingles digital ink text and typed text, and to explore the writing direction free digital ink text search method.

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References


