Pattern Recognition Letters 35 (2014) 246–255

Contents lists available at SciVerse ScienceDirect

Pattern Recognition Letters

journal homepage: www.elsevier.com/locate/patrec

More than ink — Realization of a data-embedding pen

Marcus Liwicki [a,*], Seiichi Uchida [b], Akira Yoshida [b], Masakazu Iwamura [c], Shinichiro Omachi [d], Koichi Kise [c]

[a] DFKI, Germany
[b] Kyushu Univ., Japan
[c] Osaka Prefecture Univ., Japan
[d] Tohoku Univ., Japan

ARTICLE INFO

Article history:
Available online 14 September 2012

Keywords:
Data-embedding pen
Stroke recovery
Handwriting

ABSTRACT

In this paper we present a novel digital pen device, called data-embedding pen, for enhancing the value of handwriting on physical paper. This pen produces an additional ink-dot sequence along a written stroke during writing. This ink-dot sequence represents arbitrary information, such as writer's name and writing date. Since the information is placed on the paper as an ink-dot sequence, it can be retrieved just by scanning or photographing the paper. In addition to the hardware of the data-embedding pen, this paper also proposes a coding scheme for reliable data-embedding and retrieval. In fact, the physical data-embedding on a paper will undergo various severe errors and therefore a robust coding scheme is necessary. Through experiments on data written by two writers, we show that we can embed 32 bits on short and simple or even on more complex patterns and finally retrieve them with a high reliability.

1. Introduction

Handwriting is an important modality for writing down information, making annotations, or just marking items. Unfortunately, as soon as the ink is on the paper, many information known during writing is already lost. We cannot access meta-information about the handwritten pattern from itself; it is impossible to retrieve who wrote this pattern or when it was written. In other words, a handwritten pattern on a physical paper is just an ink pattern and thus cannot provide any information but its shape.

Digital pens have emerged as a choice to store and retrieve such additional information. In fact, several digital pens capturing handwriting on normal paper have been developed. Those pens can store the stroke sequences on a computer with some additional information. Unfortunately, the digital pens cannot increase the value of handwriting on paper; even with the digital pens, the handwriting left on the paper is still just an ink pattern without any information.

In this paper, we propose a novel pen device to enrich the handwriting on the physical paper. The proposed pen device, called *data-embedding pen*, can embed arbitrary information, such as meta-information, by an additional ink-dot sequence along the ink stroke of the handwriting. Each ink-dot represents an information bit and thus an ink-dot sequence represents a bit-stream of the information to be embedded. The information can be retrieved by scanning or photographing the paper and decoding the ink-dot sequence.

The most important property of the data-embedding pen is to increase the value of handwriting on the physical paper. If we embed the writer ID, the handwriting on the physical paper itself stores this meta-information and identifies the writer without using an electronic memory. If we embed an URL into the handwriting, the handwriting becomes a link between the physical paper world and the cyber-space, i.e., the Internet. Furthermore, if we embed any temporal information or hints into the pattern, it is possible to convert the strokes into the online representation which is helpful to attain a better handwriting recognition accuracy.

The contributions by this paper are summarized as follows.

- The idea of embedding information into handwriting is very novel, as reviewed in Section 2.
- For this idea, a prototype of the data-embedding pen is implemented using a special ink-jet nozzle element. Such an implementation has never been developed before.
- For reliable data-embedding and data-retrieval, image processing techniques and a coding scheme are proposed, both of which are specialized for the data-embedding pen.
- Experimental results with the prototype proved that arbitrary 32-bit information can be embedded into, for example, a 5 cm-length handwriting pattern and retrieved perfectly from the pattern.

* Corresponding author.
E-mail addresses: marcus.liwicki@dfki.de (M. Liwicki), uchida@ait.kyushu-u.ac.jp (S. Uchida).

0167-8655/$ - see front matter
http://dx.doi.org/10.1016/j.patrec.2012.09.001

Note that this paper is not only the first compilation of the authors' past trials (Uchida et al., 2006; Liwicki et al., 2010a,b, 2011) but also a new report of experimental results on a broader set of handwritten patterns.

2. Related work

To the authors' best knowledge, the data-embedding pen is the first trial on implementing a new pen device which can embed arbitrary information dynamically into handwriting on a paper. Generally, embedding data into paper has been done statically by a printer. For example, XEROX DataGlyph (Hecht, 1994) is a kind of digital watermarks and information is printed and embedded as a fine texture into font images or photographs.

Digital pens are popular devices to enhance the usability of handwriting. Various types of digital pen devices are already available. Tablets are the most widely available digital pen-input modality. Wacom tablets,[1] for example, capture the pen-tip trajectory by a note-size flat pad with sensor array. Other digital pens use ultrasonic to capture the pen-tip location. All those digital pens are just useful to transfer handwritten patterns to the computer. In other words, they do not enhance the "function" of the handwriting on paper itself.

Nowadays, the most famous digital pen seems to be the Anoto pen.[2] Anoto reads the dot pattern printed on the paper surface from its pen-tip camera and detects its absolute position on the paper by interpreting the pattern. By continuously detecting the position during the pen movement, Anoto can acquire the online trajectory. Like other digital pens, the Anoto pen also has a very different purpose from the data-embedding pen, i.e., just transferring the pattern to the computer. In fact, the handwritten pattern on the paper is just a pattern showing a stroke shape and thus no additional value. In contrast, the purpose of the data-embedding pen is to enhance the function of the handwritten pattern on paper.

3. The data-embedding pen

3.1. Hardware prototype

The data-embedding pen is a device which comprises a usual ballpoint pen and an ink-jet nozzle element. Fig. 1 (top) depicts a prototype of this device with the ballpoint pen at the top and the nozzle at the bottom. Fig. 1(a) is a handwritten pattern generated by the prototype. During the writing, the nozzle produces small ink-dots alongside the handwritten stroke. The color of the ink-dots is different from the color of the stroke. In this paper, yellow is used for the ink-dots for better visibility of the results. Invisible ink is a good alternative for hiding the ink-dot sequence. In the past we have successfully performed experiments using invisible ink in combination with an ultraviolet camera (see Liwicki et al., 2010a).

It is possible to encode arbitrary information as an ink-dot sequence by changing the number, the timing, and the shape of the ink-dots, as shown in Fig. 1(a). Very roughly speaking, this coding scheme is similar to Morse code, where short and long segments and a pause are used and arbitrary information is represented as their sequence. Our coding scheme is designed to be more robust and error-tolerant, as described in the later sections.

The ink-dot shape can be controlled by using the high-frequency injection mode of the nozzle. The nozzle is able to generate up to 2000 ink-dots per second. Under this high-frequency mode, the ink-dots on the paper are connected and form a line segment. Hereafter, a line produced by n sequential ink-dots is called n-pulse line. If $n = 1$, the n-pulse line forms a single ink-dot. The line becomes longer by increasing n.

Note that due to hardware-specific issues the hardware of the actual data-embedding pen differs from the original setup proposed in (Uchida et al., 2006). One crucial aspect is that just one nozzle element is used, since it was not possible for us to integrate more than one nozzle element into a practicable device. However, it would be possible to do so by designing specific nozzle elements in cooperation with printer companies. Thus the contribution of this paper can be seen as proving that the data-embedding pen can be realized and therefore motivating printer companies to develop a hardware which would be able to produce smaller dots and including more than one nozzle element and thus enabling the pen to be used with smaller handwriting and to embed even more information.

3.2. Applications

Various kinds of information can be embedded into handwriting by the data-embedding pen. This means that we can consider various applications of the data-embedding pen. In this section, several possible applications will be shown. All applications make use of the fact that any data encoded in a binary sequence can be added alongside with the handwritten pattern. Depending on the length of the pattern, the amount of information varies. As shown later by the experimental results, the current prototype can embed arbitrary 32-bit information into a 5 cm-length handwritten pattern, for example.

Embedding information relating to the handwritten pattern itself is the simplest application. For example, writer's ID, writing date, and writing Geo-location, are possible candidates. This "meta"-information of the handwritten pattern can be useful for enhancing signature verification and for usage in other forensic applications. In addition, if we know the writer's ID, the recognition of the handwriting will become easier because we can apply some character recognition model tuned to the writer. Discrimination of multiple writers on a single document is also possible, if the pen embeds the corresponding writer ID. More details of this application idea as well as the idea of embedding a "handwritten" barcode linking link between physical paper world and the cyberspace are presented in (Uchida et al., 2006).

Embedding information on paper opens up new possibilities for diaries and notebooks. The owner of the book has only the paper documents at hand. However, still he or she can always find out when and where the information has been written down. Similarly, one can use the pen for writing an account of one's journey or a diary. If the pen is equipped with a GPS-receiver, the time and place will be automatically attached to the handwritten sentences. After scanning the handwritten pages, the information can be uploaded as a blog or as contributions to a Web 2.0 platform.

If we embed any temporal information by an ink-dot sequence, it is possible to relax the difficulty of the stroke recovery problem (Doermann and Rosenfeld, 1995; Kato and Yasuhara, 2000; Nel et al., 2005), which is an inverse problem to estimate the original writing order of a handwritten stroke pattern. This implies that we can convert handwritten images into online patterns and thus apply online handwriting recognition (Plamondon and Srihari, 2000; Vinciarelli, 2002), which is generally more accurate than offline recognition. Note that in this paper the writing direction, i.e., a kind of temporal information, is already embedded into the handwritten pattern for reliable data-retrieval.

Note that for enabling a pen for such applications it needs to be equipped with the application-specific hardware. While the realization of such hardware is out of the scope of this paper, we will present some ideas for realization here. As mentioned above, the pen could be equipped with a small GPS-receiver and an internal

[1] http://www.wacom.com — last visited: November 2011.
[2] http://www.anoto.com — last visited: November 2011.