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Recovery and localization of handwritings by a camera-pen based on tracking and document image retrieval

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ABSTRACT

We propose a camera-based method for digital recovery of handwritings on ordinary paper. Our method is characterized by the following two points: (1) it requires no special device such as special paper other than a camera-pen to recover handwritings, (2) if the handwriting is on a printed document, the method is capable of localizing it onto an electronic equivalent of the printed document. The above points are enabled by the following processing. The handwriting is recovered by the LK tracking to trace the move of the pen-tip. The recovered shape is localized onto the corresponding part of the electronic document with the help of document image retrieval called LLAH (locally likely arrangement hashing). A new framework for stably estimating the homography from a camera-captured image to the corresponding electronic document allows us to localize the recovered handwritings accurately. We experimentally evaluate the accuracy, processing time and memory usage of the proposed method using 30 handwritings. From the comparison to other methods that implement alternative ways for realizing the same functionality, we have confirmed that the proposed method is superior to those other methods.

1. Introduction

Even with a modern digital mobile environment, we still continue to use a classical method of recording information, i.e., handwriting by a pen on ordinary paper, when we write notes for recording ideas, comments on documents at a meeting, and so on. Although it is quite easy to produce handwritings by using the classical method, it is generally troublesome to convert the resultant handwritings to digital data for later use of editing and sharing; it requires at least scanning and recognizing the handwriting. Thus it is advantageous to have a mean to digitize the handwriting automatically while keeping easiness and simplicity of the classical method.

For achieving this goal, many methods and systems have been developed. A successful example is the Anoto system (http://www.anoto.com/) which enables us to digitize the handwriting by using a camera mounted on a pen and special paper with a number of fine dots on its surface. The uniqueness of local point distribution enables the system to find the absolute position, i.e., the information on which sheet of paper and where on the sheet the pen is working. The system can recover the handwriting by tracing the absolute position of the pen-tip. Although this system is in practical use, its drawback is the requirement of special paper.

The above problem can be solved by realizing the same functionality without special paper, which can be decomposed into the two processes shown in Fig. 1. One is to trace the pen-tip movement without using special paper. We call it "recovery" of handwritings. In addition, as a replacement of knowing the absolute position, it is required to relate handwritings to known documents. Suppose the case that the user is writing on a printed page of a document whose electronic version is also available. In this case the user would like to reflect the handwritings to the corresponding positions of their electronic equivalents. We call it "localization" of recovered handwritings. Needless to say, this should also be done without the use of special paper.

As a trial to realize the above functionality, we have proposed a method that employs both the paper fingerprint, i.e., microscopic structure of paper surface, and printed patterns on documents (Iwata et al., 2010). In this method, the paper fingerprints are traced by using the tracking of SURF features (Bay et al., 2008) (SURF tracking). In addition, printed patterns are used as a clue to find the corresponding electronic document as well as to find the location at which the handwriting is generated. Although this method requires no special paper there still remains a problem of accuracy; the shape of recovered handwriting is not accurate enough and sometimes fails to locate the recovered handwriting on the document.

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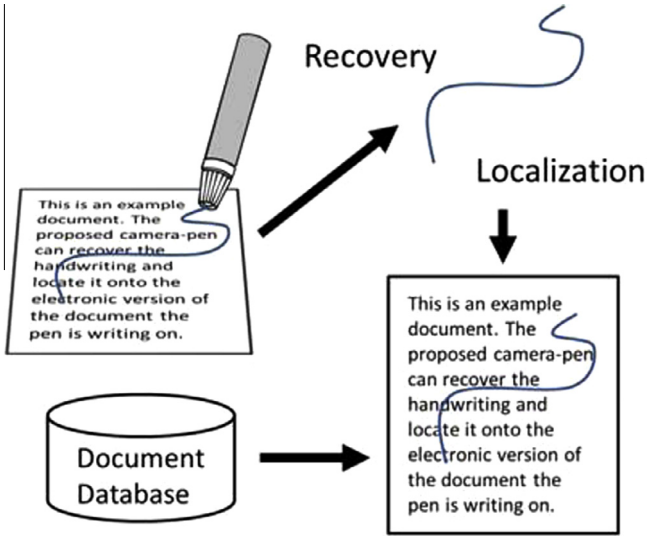

Fig. 1. Processes required for camera-pens.

In this paper, we propose a new method that overcomes the above problems. For the improvement of handwriting recovery, we introduce a tracking based on Lucas-Kanade Method (LK) (Lucas et al., 1981) (LK tracking) instead of the SURF tracking. This allows us to improve the stability of tracking so that the shape can be recovered more smoothly. Accuracy of document image retrieval is also improved by the query expansion (Kise et al., 2010) as well as a new framework of estimating the homography from a camera captured image to the retrieved document image. This is achieved by unifying the result of tracking and that of retrieval. Experimental results on 30 handwritings, we have confirmed that the proposed improvements are promising as compared to our previous method (Iwata et al., 2010) as well as other methods that implement possible alternatives for realizing the same functionality.

The main contribution of this paper is the proposal of an overall framework for camera-pens without special paper. In our previous trials (Kise et al., 2009, 2010; Iwata et al., 2009, 2010; Uchida et al., 2009) we have examined different technologies. This paper shows the best combination of fundamental technologies including newly introduced such as the LK tracking. More importantly, we propose a new method of stably estimating the homography which is mandatory to the localization. The technological breakthrough achieved by the above points enables us to improve the accuracy of recovered handwritings significantly. This has been confirmed by the experimental results with a much larger number of handwritings compared to the previously reported results (Kise et al., 2009, 2010; Iwata et al., 2009, 2010; Uchida et al., 2009).

In order to make use of the proposed method as a part of a camera-pen system, it is also required to judge the state of pen up and down. In addition, as an important application, the recovered handwritings should be recognized if they are characters. However, this paper does not deal with these issues due to the following reasons. For the former point, the state of pen up and down is not necessarily determined by only using image processing. Rather it would be easier to use a micro switch to sense the touch to a paper surface by the pen-tip. For the latter point, the discussion can be safely separated since existing technologies of on-line handwriting recognition can be applied once the handwriting has been recovered.

The organization of this paper is as follows. In Section 2, we review the existing methods to clarify the problems to be solved. Section 3 is devoted to describe the goal of the proposed camera-pen system. In Section 4, we briefly review the document image retrieval employed in the proposed method. Section 5 is the main part of this paper to describe the details of the proposed method. Experimental results are shown in Section 6. In Section 7 we sum up what we have learned as well as mention the future work.

2. Related work

In order to bridge the gap between handwritings on paper and digital media that stores the handwritings digitally, there have been many efforts that can be divided into commercial and research developments.

As commercial systems, we focus here on the following three systems.

The first one is a tablet system that uses electromagnetic induction to capture the pen-tip movement (e.g., http://www.adesso.-com/home/tablets/158cyberpad.html). When this system is used, paper is placed on the tablet and the pen-tip movement is traced by the tablet while the user writes his/her handwriting on the paper. Although the accuracy is high, its portability and simplicity is limited.

The second is a system with a small device that emits the ultrasonic sound and/or infrared light and a special pen (http://www.pegatech.com/). The device measures the reflection from the special pen to know its position. Although it is more portable than the tablet, this has an important disadvantage: since it only measures the relative position between the device and the pen assuming that the device is fixed onto the sheet of paper, the recovery becomes impossible if the position of the device on the sheet changes.

The third is the Anoto system. It employs a camera-pen and special paper with fine dots. It captures the local distribution of fine dots to decode the global position of the pen-tip. This is the most advanced commercial system with respect to the portability and the reliability: only the camera-pen is necessary for users to carry, and no inaccuracy was caused in measuring the global position. However this still has a limitation that it requires special paper; it is not possible for users to write on ordinary paper.

As for research systems, one of the very first systems is PaperLink (Arai et al., 1997). It was proposed to establish the relation between a printed document and electronic data. Although this system works on ordinary paper, it only enables the connection from printed words; no handwriting is allowed.

As systems allowing handwriting, we introduce the following three systems. The first is a signature verification system (Yasuda et al., 2008). This system employs two cameras fixed on frontal and side positions of a sheet of paper for capturing images of the pen-tip. Tracking using the captured images enables to recover the handwriting, which is used for signature verification. The second system is proposed by Munich et al. (2002) to recover handwritings and sketches. In this system, a camera fixed in the environment captures the paper surface as well as the process of writing. Tracking allows us to recover the trajectory of the pen-tip, which is regarded as the handwriting. The third is a system proposed by Seok et al. (2008) which tracks the pen movement on printed documents similarly to the system by Munich.

The advantage shared by the above three methods is that they require no special pen nor paper. On the other hand, the cameras must be fixed in the environment. This spoils their portability. In addition, before using the system, the camera must be calibrated.

Pens equipped with cameras have also been researched.

An example is a camera-pen by tracking paper fingerprints (Uchida et al., 2009). In this method, SURF features (Bay et al., 2008) are extracted from the paper fingerprint and matched between succeeding frames so as to obtain the pen-tip movement. Its advantage comes from the reproductivity of the SURF features.