Chapter 17
Recovering Drawing Trajectory
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ABSTRACT
Graph theory has many applications in solving real-life problems. However, the application of Eulerian graphs and Eulerian tours/trails seems to be comparatively limited. In this chapter, an application of graph theory in handwriting recognition is presented. There are a lot of studies regarding handwriting recognition. Most of these methods deal with either offline or online handwriting recognition. However, the discussed approaches in this chapter are distinct in the manner that they aim to extract the trajectory of writing so as to equip the offline handwritten image with temporal information. When the trajectory of writing is known, it can be possible to utilize online recognition methods which are more reliable. These trajectory extracting methods are based on Eulerian trails in semi-Eulerian graphs. Semi-Eulerian graphs are graphs with at most two odd vertices. Eulerian trail is a trail in which every edge is traversed exactly once. The methods can be helpful in recognition of single-stroke handwritten images. Relying on the minimum energy law, the methods try to find the smoothest trajectory of writing which contribute to the recognition process.

INTRODUCTION
In the digital computers era, keyboards carry out some part of writing duty. However, typing is not as convenient and fast as traditional method of writing with pen. Hence, in situations where the time and ease of writing are important, people still prefer to use their own handwritings. Many times, these handwritten texts are needed to be scanned, recognized and processed by a digital computer. The conversion of scanned images to recognizable texts makes them editable and searchable, and allows the text to be stored in a more compact file. Thus, handwriting recognition is necessary to transcribe the graphical marks to understandable symbols for a digital processor. Legal industry, healthcare organizations, postal departments and banking industry are some of the environments which utilize this transcription.

The recognition of scanned image of text is called offline handwriting recognition. Contrarily, in the online handwriting recognition the writing process is being done on an electronic surface. When working with offline handwriting, all we
have to recognize the text is a two dimensional image in which each pixel (point) has two coordinates: abscissa and ordinate. On the other hand, in online writing each point carries one additional coordinate: the time of writing. In other words, in online handwriting the trajectory of writing is known. By the perception of trajectory of writing, offline handwriting can be dealt with as online. This conversion is worthwhile since the recognition by online algorithms is more reliable.

In this chapter, we focus on this problem: identifying the pen tip trajectory in order to convert the offline handwritten images into online hardwiring.

A scanned offline handwritten image is a collection of black (i.e. written) and white (i.e. blank) pixels. Here we suppose that the pen-tip width is one pixel. In reality, the pen-tip width is greater than one pixel. Hence, a thinning procedure should be performed to reduce the handwriting width to one-pixel (Cheriet, Kharma, Liu, & Suen, 2007). The thinned handwriting is called the skeleton of handwriting. Since this procedure is not related to the application of Eulerian graphs, we omit it.

We suppose further that the handwriting is single-stroke. Every stroke is created by putting the pen-tip on the paper, moving the pen over the paper, and removing the pen from the paper. So, for example the capital letter X is not single stroke. Single-stroke handwriting is very popular in English cursive writing.

**BACKGROUND**

Handwriting recognition is vital at least so long as the individuals write on papers or digital surfaces. In a comprehensive survey, Plamondon and Srihari reviewed many of online and offline approaches in handwriting recognition (Plamondon & Srihari, 2000).

Vinciarelli and Perrone proposed a combined method for recognition of online handwriting (Vinciarelli & Perrone, 2003). In their approach, first the online handwriting is recognized by an online system. Then, it is converted to a bitmap image and is recognized by an offline recognizer. By combining both results, the ultimate recognition becomes available which is more reliable than each individual result.

Trajectory recovery is an approach of extracting the chronology of writing of segments in order to enhance the reliability of offline handwriting recognition. An up-to-date review of trajectory extraction of offline handwriting approaches including analysis of different input types (skeleton or contour), end point detection, and trajectory recovery is presented by Nguyen and Blumenstein (Nguyen & Blumenstein, 2010). Nel uses Hidden Markov Models to estimate the trajectory of handwritten image (Nel, 2005). HMM is a probabilistic model which describes the dynamic transition between states. Her numerical results show that the method is both accurate and robust.

Graph-based analysis of offline handwritten image is a very common approach especially in the recovery of chronology of writing. Qiao and Yasuhara used a template match method to extract the trajectory of writing in multi-stroke handwritten images (Qiao & Yasuhara, 2006b). Their approach includes finding terminal vertices, searching for the best matching between terminal vertices, and insertion of missed vertices into the path. Rousseau et al. combined minimum curvature criterion with four other criteria in order to extract a reliable trajectory of strokes for the graph corresponding to the skeleton of single letter images (Rousseau, Anquetil, & Camillerapp, 2005). Rousseau et al. continued their study on multiple-stroke images (Rousseau, Camillerapp, & Anquetil, 2006). The steps of their approach include segmentation, ordering the graphs, choosing start/end points, pruning of incompatible paths, and sorting the paths.

When the skeleton of the handwritten image is converted to a graph, the concepts of Eulerian tours and trails can be used to recognize the trajectory of writing. Based on the methodology used in Chinese Postman Problem, Cordella et al. converted
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