BOOK BOUNDARY DETECTION FROM BOOKSHELF IMAGE BASED ON MODEL FITTING

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ABSTRACT

Several systems based on bookshelf image analysis have been studied for automating bookshelf inspection in libraries and bookstores. In conventional systems, book boundaries are firstly detected for extracting each individual book by using some popular line detection technique, such as Hough transformation. Their detection accuracies, however, are sometimes insufficient. In this paper, we propose a model-based book boundary detection technique for higher detection accuracy. The model is represented as a finite state automaton, each of whose states corresponds to a component of bookshelves, such as boundary and title. With this model, the book boundary detection problem is formulated as a model-based optimization problem where states and local slant angles at all horizontal positions were variables to be optimized. The globally optimal solution is efficiently searched for using a dynamic programming based algorithm. The effectiveness of the proposed technique was shown by several experiments.

1. INTRODUCTION

Inspection of bookshelves for managing libraries and bookstores is a time-consuming and tedious task. This is because there are enormous books in the bookshelves and many of those books are moved frequently and repeatedly. For automating the bookshelf inspection, several systems based on bookshelf image analysis have been studied [1]–[5]. The goal of those systems is to extract individual book information, such as title, from bookshelf images.

For this goal, book boundaries are firstly detected by some popular line detection technique in the conventional systems. For example, Hough transformation on the edge map of a bookshelf image is employed for detecting contiguous and straight edges which correspond to the book boundaries. Unfortunately, the detection accuracies of the conventional techniques are sometimes insufficient. This is because book boundaries are often missed due to the lack of boundary edges caused by ill lighting conditions and contiguities of books of the same color. In addition, spurious boundaries are often detected due to the edges around title characters on book spines.

In this paper, we propose a model-based book boundary detection technique. For higher detection accuracy, a finite state automaton (FSA) model is employed, which describes the structural properties of bookshelves. Roughly speaking, each state of the FSA model corresponds to a component of bookshelves, such as boundary and title. With this model, the book boundary detection problem is expressed as a model fitting problem to identify the state (i.e., the component) at each horizontal position. Finally, the horizontal positions identified as the boundary state are detected as the book boundaries.

For the practical boundary detection, it should also be taken into account that books have their individual slants. For coping with non-uniformly slanted books, the slant angle at each horizontal position should be estimated optimally. Consequently, the book boundary detection problem is formulated as a model-based optimization problem of both the state and the local slant angle at each horizontal position. The globally optimal solution is efficiently searched for using a dynamic programming (DP) based algorithm.

2. BOOK BOUNDARY DETECTION TECHNIQUE BASED ON MODEL FITTING

2.1. Problem formulation

Consider a bookshelf image such as **Fig. 1**(a). As shown in **Fig. 1**(b), bookshelf images have several components, i.e., the boundary, the spine, the title, and the

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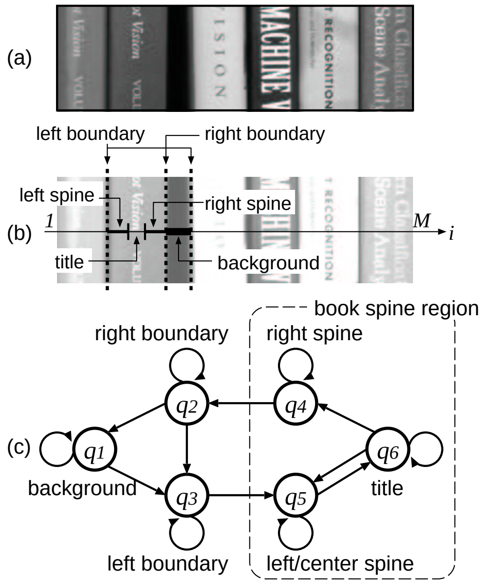

Fig. 1. (a) A bookshelf image. (b) The structural properties of (a). (c) An FSA representation of (b).

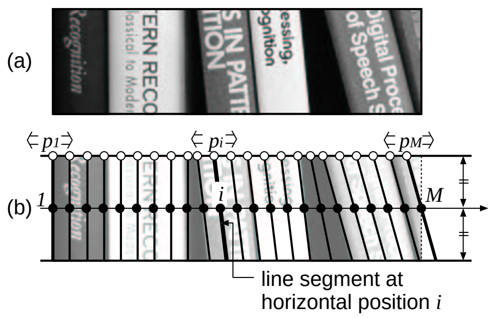

Fig. 2. (a) Non-uniformly slanted books. (b) A sequence of line segments representing the slants of books.

bookshelf background, and the order of those components is naturally governed by some rules. The rules can be represented by an FSA model composed of 6 states ($\boldsymbol{Q} = \{q_1, \ldots, q_6\}$), each of which corresponds to one of those components, as shown in **Fig. 1**(c). With this model, the book boundary detection problem is expressed as a model fitting problem, i.e., a model-based optimization problem of the sequence $s_1, \ldots, s_i, \ldots, s_M$ where $s_i \in \boldsymbol{Q}$ denotes the state identified at horizontal position i.

For coping with non-uniformly slanted books (**Fig. 2**(a)), we should also consider the optimal estimation of the sequence $p_1, \ldots, p_i, \ldots, p_M$ where p_i is the integer variable to represent the local slant angle at horizontal position i. As shown in **Fig. 2**(b), $p_i \in [i - W, i + W]$ is the horizontal position of the top end of the line segment which passes through the

/* Initialization: */
for all $s_1 \in \boldsymbol{Q}$ **do**
  for $p_1 := 1 - W$ **to** $1 + W$ **do**
    $g_1(s_1, p_1) := f_1(s_1, p_1)$
/* DP Recursion: */
for $i := 2$ **to** M **do**
  for all $s_i \in \boldsymbol{Q}$ **do**
    for $p_i := i - W$ **to** $i + W$ **do begin**
      $g_i(s_i, p_i) := f_i(s_i, p_i) + \max\limits_{s_{i-1}, p_{i-1}} g_{i-1}(s_{i-1}, p_{i-1})$
      $bp_i(s_i, p_i) := \operatorname*{argmax}\limits_{s_{i-1}, p_{i-1}} g_{i-1}(s_{i-1}, p_{i-1})$
    end
/* Backtracking: */
$(s_M^{\mathrm{opt}}, p_M^{\mathrm{opt}}) := \operatorname*{argmax}\limits_{s,p} g_M(s, p)$
for $i := M$ **downto** 2 **do**
  $(s_{i-1}^{\mathrm{opt}}, p_{i-1}^{\mathrm{opt}}) := bp_i(s_i^{\mathrm{opt}}, p_i^{\mathrm{opt}})$

Fig. 3. DP algorithm.

center of the ith column, where W is a positive integer to specify compensable slant angles. For practical simplicity, we use p_i instead of some real-valued angle.

The optimization problem of sequences of s_i and p_i is formulated as the following maximization problem,

$$\begin{array}{ll} \textbf{maximize} & \displaystyle\sum_{i=1}^{M} f_i(s_i, p_i), \\ \textbf{w.r.t.} & s_i, p_i \ (i = 1, 2, \ldots, M), \end{array} \tag{1}$$

subject to the transition rule of the FSA model and a constraint to limit the interval between p_i and p_{i-1},

$$p_i = \begin{cases} p_{i-1} + 1 & \textbf{if } s_i \in \{q_4, q_5, q_6\} \\ & \quad \textbf{or } s_{i-1} \in \{q_4, q_5, q_6\}, \\ p_{i-1} + \{0, 1, 2\} & \textbf{otherwise}. \end{cases} \tag{2}$$

With this constraint, angle fluctuations are not allowed at book spine regions. This means the book spine regions have their fixed slant. On the other hand, at book boundaries and bookshelf background regions, the angle fluctuations are allowed, while its degree is limited.

The function $f_i(s_i, p_i)$ is a criterion function to evaluate the validness of s_i and p_i at horizontal position i. This function is based on the edge feature on the line segment at horizontal position i. For example, since long contiguous near-vertical edges are often detected around book boundaries, $f_i(q_2, p_i)$ and $f_i(q_3, p_i)$ are designed to take larger value if there are many and/or long near-vertical edges on the line segment.

2.2. Solution by DP

The sequential optimization process of s_i and p_i noted in Section 2.1 has the Markov property. This is because

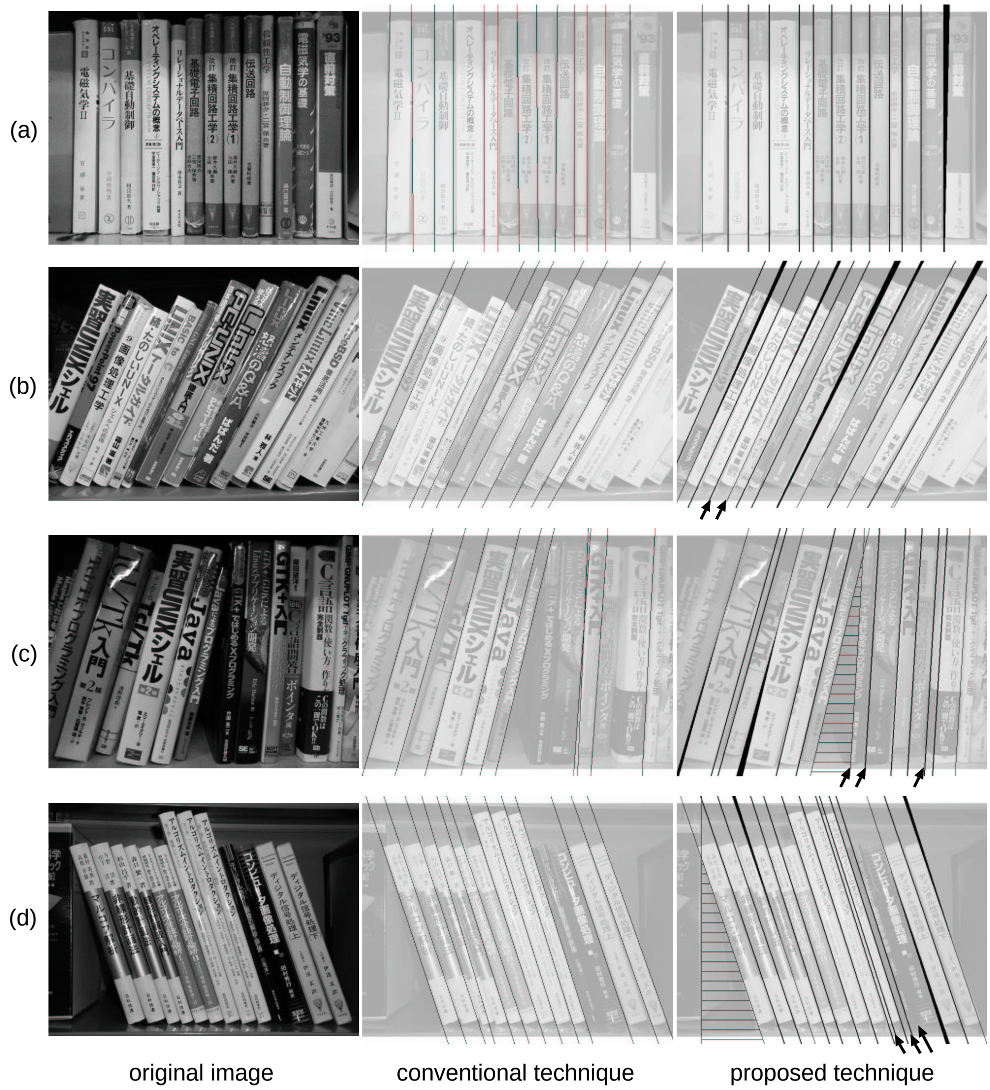

Fig. 4. Examples of book boundary detection. For each image, the original image (left), the result by the conventional technique A (middle), and the result by the proposed technique (right) are shown. The book boundaries detected are shown as black lines, and the bookshelf background regions detected by the proposed technique are shown as horizontal hatchings. In (b) and (c), the boundaries correctly detected only by the proposed technique are indicated by arrows. In (d), the boundary missed and the spurious boundaries detected by the proposed technique are indicated by arrows.

only two values s_{i-1} and p_{i-1} are necessary for determination of s_i and p_i, and the other past values are not necessary. It is well known that the optimization problem with the Markov property can be efficiently solved using DP.

Figure 3 shows a DP algorithm for the maximization problem (1). Step 7 is so-called DP recursion, and its two variables s_{i-1} and p_{i-1} are restricted by the FSA model (**Fig. 1**(c)) and the constraint (2). The optimized s_i and p_i, denoted as s_i^{opt} and p_i^{opt} respectively, are obtained by the backtracking procedure Step 10–12. Finally, if s_i^{opt} equals to q_2 or q_3, the line segment at horizontal position i is detected as a book boundary, which is slanted at the angle specified by p_i^{opt}.

3. EXPERIMENTAL RESULTS

Experiments for evaluating the proposed technique qualitatively and quantitatively were conducted. For the experiments, 60 bookshelf images were prepared. Then Canny edge detector was performed on each bookshelf image.

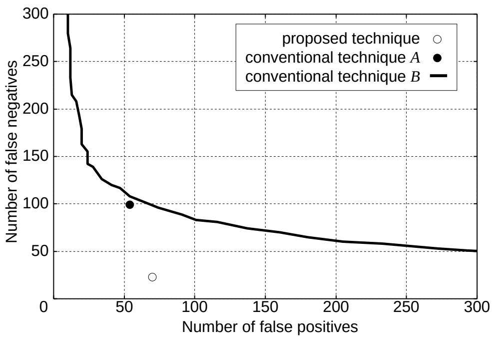

Fig. 5. Number of false positives and false negatives.

In the following two experiments, the proposed technique was compared with the conventional technique [5] using Hough transformation. The conventional technique has two versions; in the first version (hereafter called "conventional technique A"), the threshold to find local maxima in Hough parameter space is adaptively decided depending on the result of voting to Hough parameter space. In the second version (hereafter called "conventional technique B"), the threshold is fixed at a manually determined value regardless of the result of voting.

3.1. Qualitative Evaluation

Figure 4 shows several results by the conventional technique A and the proposed technique. **Figures 4**(a), (b), and (c) show that the proposed technique can detect most book boundaries correctly. Especially in (b) and (c), it is shown that the proposed technique can detect all boundaries of slanted books while the conventional technique A fails.

As shown in **Fig. 4**(d), the proposed technique sometimes misses some boundaries (false negative) and detects spurious boundaries (false positive). The former is mostly because the colors of adjacent books are similar each other and therefore boundary edges are entirely lacked. The latter mostly resulted from contiguous edges around title characters and areas reflecting some light.

3.2. Quantitative Evaluation

Figure 5 shows the number of false negatives and the number of false positives. In the graph, "" and "" show the results by the proposed technique and the conventional technique A, respectively. The evaluation of the conventional technique B was conducted while changing the threshold to find local maxima, and therefore its result is shown as a curve line in the graph.

The number of false negatives by the proposed technique was 3.2% (= 23/727) of all book boundaries and far less than 13.6% (= 99/727) of the conventional technique A. This number was less than the half of that by the conventional technique B even when 300 false positives were allowed. On the other hand, the number of false positives by the proposed technique was slightly more than that by the conventional technique A. The reduction of the false positives is remained as future work.

4. CONCLUSIONS

A novel book boundary detection technique using a bookshelf model was proposed in this paper. The model was represented as a finite state automaton based on the structural properties of bookshelves. The book boundary detection problem was formulated as a model-based optimization problem where states and local slant angles at all horizontal positions were variables to be optimized and then solved efficiently using a dynamic programming based algorithm. Experimental results show that the proposed technique has superior detection performance than the conventional techniques. The results also show that the reduction of spurious boundaries is the remaining problem.

5. REFERENCES

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