

# Correcting Common Distortions in Camera-Imaged Library Materials

Michael S. Brown and Desmond Tsoi  
Department of Computer Science  
H.K.U.S.T.  
Clear Water Bay, Hong Kong

## ABSTRACT

We present a technique to correct image distortion that can occur when library materials are imaged by cameras. Our approach provides a general framework to undo a variety of common distortions, including binder curl, fold distortion, and combinations of the two. Our algorithm is described and demonstrated on several examples.

**Keywords:** Digital collections; distortion removal

## 1. INTRODUCTION

Camera-based imaging of library materials is becoming increasingly common. This non-contact imaging technique is particularly useful for items such as paintings, rare documents, and other media that are too large or fragile for flatbed scanners. Because these items are not physically pressed flat when imaged, their underlying shape cannot be guaranteed to be flat. This can cause what is perceived as distortion. One well-known example is the curl distortion present near the binding of a book. Other examples include distortion from folded pages (see Figure 1).

Techniques to correct this distortion are desired to make the imagery more visually appealing and to facilitate subsequent post-processing, such as OCR. In this paper, we provide a novel approach to undo common distortions encountered in camera-imaged library materials.

## 2. RELATED WORK

The term “skew” is used to describe the presence of distortion in an imaged document. Currently, there are two fundamental “de-skewing” algorithms. The first targets mis-aligned documents imaged on a flat-bed scanner. These algorithms compute planar transforms to align the scanned content to the image’s raster representation [4]. The second common de-skewing approach corrects the paper curl effect that occurs near a book’s binding. Because assumptions can be made about the physical properties that cause this distortion, for example, the page is always curled in a cylindrical fashion, this problem is fairly well defined and commercial solutions exist [5].

While planar and book-binding skew can be corrected, these types of distortions are specific to bound books and loose document collections. Items that warrant camera-imaging often introduce more complex distortions that cannot be corrected by these techniques. For example, the image in Figure 1(b) of a three-page fold-out exhibits distortion from both folding and binder curl. This distortion *cannot* be corrected using current de-skewing algorithms. Distortion after imaging such materials remains a problem.

Some recent approaches have addressed arbitrary distortions. These techniques work by extracting 3D information about the imaged material. Brown et al [1,2] recovered 3D points on a

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, to republish, to post on servers, or to redistribute to lists, requires prior specific permission and/or a fee.

JCDL '03 May 1-2, 2003, Houston, Texas.

Copyright 2000 ACM 1-58113-000-0/00/0000...\$5.00.



Figure 1: Examples of image distortion. (a) book binder distortion (b) a more complex example of a three page fold-out.

material’s surface and used a physics-based simulation to virtually “flatten” the material back to a plane. Pilu [5] provided a similar solution in which sparse 3D data of a document’s surface was captured and used to construct a triangulated 3D mesh. A relaxation algorithm pushed the points to a plane while maintaining equal distance between the points. While these techniques do correct arbitrary distortions, they have two drawbacks. First, additional imaging equipment is needed to acquire 3D information. Second, the algorithms used are computationally slow.

In this paper, we propose a correction algorithm that uses only 2D information. Our approach works by extracting boundary information of the distorted image. Using these boundaries, we can compute a corrective function to map the distorted image to a rectangular image using boundary interpolation. This boundary interpolation approach provides a general solution that can be used to correct many common types of distortion including paper-binding curl, paper folds, and fan-like distortion.

## 3. OUR APPROACH

### 3.1 Assumptions

Two assumptions are made: (1) the imaged material was originally planar and recti-linear, and (2) the boundary information can be used to describe the deformation. Our first assumption is valid for the majority of library collections. As we will demonstrate, our second assumption is true for common distortions encountered in imaging, including binder curl and fold distortion. We note that our approach cannot correct for completely arbitrary distortion, such as an image of a crumpled piece of a paper. Currently, only the techniques that utilize 3D information [1,5] have shown promise in correcting this type of distortion. Such severe distortion, however, is found in only a small number of items. We, instead, focus on correcting *common* distortions using 2D information.

### 3.2 Boundary Representation

Our correction procedure begins by identifying the boundary of the imaged material. Since it is assumed that the item is recti-linear, only four boundaries need to be extracted. Due to the imaged

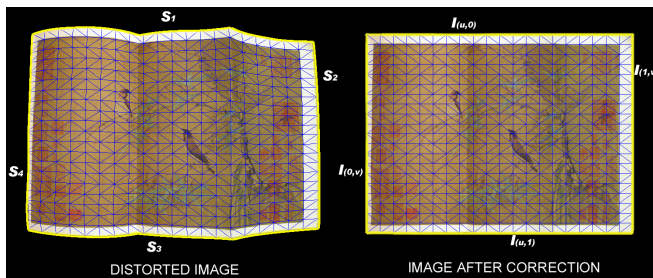


Figure 2: Four boundaries curves,  $S_1$ - $S_4$ , are identified in the distorted image. These correspond to the edges in the corrected image. A triangulated mesh guides texture-mapping between the distorted image and the corrected image.

material's non-planar shape, these edges will not appear as straight lines, but instead as curves.

Boundary extraction can be done manually, by using a graphical interface, or by using imaging processing tools such as the "magic lasso" in Adobe Photoshop. If the material is imaged with a high-contrast background, automatic extraction routines can be used.

The boundary is represented by four curves:  $S_1$ ,  $S_2$ ,  $S_3$ ,  $S_4$  as shown in Figure 2. Discrete points on the extracted boundary are used to define a natural cubic spline (NCS), denoted as follows:

$$S_i(t) = \begin{cases} S_i x(t) & t \in [0,1] \\ S_i y(t) & t \in [0,1] \end{cases}$$

Mathematically, the NCS is a parametric function,  $S_i(t)$ , that provides a continuous representation of the boundary curve (see [3] for an overview on splines). With this representation, the  $(x,y)$  image coordinates on the boundary curves can be obtained by evaluating the spline function,  $S_i(t)$ , with a parameter,  $t$ , over the interval  $[0-1]$ .

### 3.3 Distortion Correction

The boundary curves,  $S_1$ - $S_4$ , in the distorted image correspond to the boundary of an undistorted recti-linear image. We have used  $(x,y)$  to represent 2D image points in the distorted image; we use  $(u,v)$  to represent 2D image points in the restored image,  $I$ . For simplicity, the restored image is defined from  $u \in [0,1]$  and  $v \in [0,1]$ . In Figure 2, we can see that the 2D  $(x,y)$  image points along the boundary of  $S_1(u)$  should map to the restored image axis, defined as  $I(u,0)$ . This correspondence holds for the other curves, e.g.,  $S_2(v)$  should map to  $I(0,v)$ . Thus, the mapping of the distorted boundary curves to their correct locations in the undistorted image,  $I$ , is known. What is needed is a 2D function,  $S(u,v)$ , which returns internal  $(x,y)$  points within the distorted image's boundary. Since the only available information is the four boundary curves, the function  $S(u,v)$  must be defined as a combination of  $S_1$ ,  $S_2$ ,  $S_3$ ,  $S_4$ . This can be realized using a boundary interpolation technique known as Coons patch interpolation [3] as follows:

$$S(u,v) = [1-u \quad u] \begin{bmatrix} S_1(v) \\ S_2(v) \end{bmatrix} + [S_3(u) \quad S_4(u)] \begin{bmatrix} 1-v \\ v \end{bmatrix} - [1-u \quad u] \begin{bmatrix} S_1(0) & S_2(0) \\ S_3(1) & S_4(1) \end{bmatrix} \begin{bmatrix} 1-v \\ v \end{bmatrix}$$

Using this function  $S(u,v)$ , we can compute the  $(x,y)$  locations of equally sampled  $(u,v)$  points in the restored image. By constructing a triangulated mesh of the sampled points, we can texture-map triangles from the distorted image to the restored image (see Figure 2). This texturing process performs the distortion correction.

## 4. RESULTS

Figure 3 shows results of our approach on three examples. The first two are the examples shown in Figure 1. These are pages (including a three-page fold-out) from two oversized books. The last image is of a 2.5x1 meter Chinese paper cut. This medium is pasted on a folded tablet. To fit inside the display case, the item cannot be completely unfolded, which is apparent in the image. Our approach is able to correct these different distortions.



Figure 3: Results from three examples. (Top) Correction of two over-sized books imaged by a camera (from Figure 1). The first corrects binder distortion. The second corrects both binder and fold distortion. (Bottom) A Chinese paper-cut on a folded tablet - before and after correction.

## 5. CONCLUSION

We have presented an image distortion correction algorithm that is suitable for correcting common distortions encountered in imaged library materials. This technique is particularly useful for camera-imaged items that cannot be physically flattened before imaging. Our algorithm requires only the imaged material's 2D boundary information to be extracted. Boundary interpolation is used to provide a general framework that can correct a variety of common distortions.

## 6. REFERENCES

- [1] Brown, M. S. et al. "Document Restoration Using 3D Shape", *Int'l Conference on Computer Vision (ICCV'01)*, Vancouver, July 2001.
- [2] Brown, M. S. et al. "Digital Atheneum: New Approaches for Preserving, Restoring, and Analyzing Damaged Manuscripts", *JCDL '01*, Roanoke, June 2001.
- [3] Farin, G. "Curves and Surfaces for Computer-Aided Geometric Design", *Academic Press*, 4<sup>th</sup> Edition, 1997.
- [4] Gatos, B. et al. "Skew detection in line position determination in digitized documents", *In Pattern Recognition*, 30(9):1505-1519, 1997.
- [5] Pilu, M. "Undoing Paper Curl Distortion Using Applicable Surfaces", *Computer Vision and Pattern Recognition (CVPR '01)*, Hawaii, Dec 2001.
- [6] US Patent 5,084,611, "Document Reading Apparatus for Detection of Curvature in Documents", *Minolta Camera, Kabushiki Kaisha*, Jan 1992.