Practical Introduction of Image Processing Technology to Digital Archiving of Rare Books

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Abstract

First, we give an outline of activity of the *Humanities Media Interface (HUMI) Project* in this paper. This project was established by Keio University for the purpose of digital archiving of rare books held in Keio University Library and of realizing a research oriented digital library. Then we show some examples of problems and requirements in digital archiving of rare books. Subsequently, we show a solution of one of these problems by proposing an adjustment method to obtain just front view of page using the 3-D information extracted from the shape of top line of the page area depicted in the image. This method is extended for partly photographed images of a page as preprocess of joining them together.

1. Introduction

By the progress of computer performance, cost down of electric/magnetic recording media and wide spread of networking environment, digital libraries that had been only concept till a few years ago begin working practically[1]. So digital libraries serve not only with text-based information or still pictures but also with sounds, music and moving pictures from their hyper-media databases through networks, that many kinds of digital information processing technologies are introduced to realize effective digital libraries[2]. Technology of digital archiving, in other words how to digitize the objects and store the digital data to the archives, is one of the most important to realize digital libraries.

Keio University where the authors are studying has many rare books in the library. When Keio University came to posses the Gutenberg 42-line Bible in April 1996, an internal preparatory project envisioning to produce a research oriented digital library was started. This project was named the Humanities Media Interface Project, commonly called “HUMI Project”[3]. In this paper, activity of the HUMI Project is outlined and some problems and requisitions that have been found in our activity are indicated. The latter half is assigned for present a solution of one of those problems : pages are photographed in digital images as curving or sloping surfaces because rare books must not be pressed down by reason of their scarcity and fragility.

2. Outline of the HUMI Project

Keio University envisions a digital library for the purpose of serving the digital archives made from the students and researchers of the humanities. Mainly, members from three faculties - of literature, of science and technology, and of environmental information - in the university join in the HUMI Project and exchange opinions form their special field to construct research oriented digital library. Our envisioning digital library is oriented to studies in the humanities field, the members from the faculty of literature are taking a leading part. The important subject for the members form the faculty of environmental information is to support by setting up the environment where the researchers make effective use of computer networks and virtual-reality technology. And we, the members from the faculty of science and technology, have principally three works in the HUMI Project;

1. Study about how to build valuable digital archives of the objects in our library and to make digital archives practically.
2. Analysis of rare and historical book materials by non-destructive approach using digital image processing.
3. Assistance of the researchers of the field of literature to make studies using digitized data of rare books and old artistic objects.

Last year, first year of the HUMI Project, the members had been working to set up the environment for activities of the project and had many discussions to realize a digital library. We also digitized rare books by super high definition camera[4] to find what problems are in making of valuable digital archives and open the archives experimentally to the Internet[5]. In order to inform about our activities and collections in the library of our university, we held exhibitions open to the public. We almost have finished the problem finding as the first stage of the activity of our project, and we are now working mainly to discuss and analyze the problems and requirements. Some experimental methods are developed day by day.

3. Problems and Requirements in Digital Archiving of Rare Books

When an image based digital archive is made, there are three steps in the process as usual. In the first step, objects are digitized and digital images are obtained. In the next step, the images are adjusted by applying some image processing methods such as trimming, color correction, geometrical transformation, color-level conversion, etc. In the last, adjusted images are encoded in order to reduce their redundancy and improve the availability by suitable image coding method. Therefore, how to apply the methods of image processing including image coding is very important to make an image-based digital archive. To make valuable digital image archives of rare books, we have found problems and have got requests from the researchers of rare books in the HUMI's activity, and some examples of those are as follows:

Problem of curved page image: Rare books are very precious and fragile. Accordingly, we must take digital images of the pages in rare books by camera with their unstrained posture. Depicted page surface in the image taken in this situation does not form an exact rectangle but has swollen curved top and bottom edge lines and contents of the page have been contorted.

Requirement for high resolution: Because researchers of rare books study not only the text-based information but also the material of pages, forms of characters, etc., high resolution images are necessary in the digital archives of rare books. To obtain a page image of sufficient resolution for this purpose, some partial images of the page of lower resolution should be joined together.

Requirement for clear image: Characters in rare books are sometimes hard to read because color of paper have changed brown or ink of character have become fainter in the long-term preservation. Adequate digital image processing for the page image will improve the readability.

Problem of color expression: So a strong light gives damage to rare books that the color of image taken by camera does not match the natural color of the object. Further, shade areas are often exist on page surface. Color and intensity adjustment should be applied to image.

Problem of conventional image coding: Because the property of page image of rare books is much different from the property of natural scene, conventional image coding method, such as JPEG, does not give high performance. However, it is unwelcome to apply binary image coding method because color information is important for the researchers of rare books. Special coding method for page image of rare books must be studied.

4. Adjustment Method for Curved Page Image

Most of rare books, for example the Gutenberg Bible, are hardbound and their leaves have been rigidly pasted to spines. Therefore, when we want to get a page image of a rare book, we can not open it widely enough to obtain a image of flat page surface because of the risk to break the book.

In the pages that follow, an image adjustment method in order to get rectangular just-front view of a page is proposed. By this adjustment, image of rounded page surface taken by high definition digital camera is geometrically compensated to make a rectangular page view just like a view of detached leaf.

4.1. Case of a Whole Page in an Image

The image input device is shown in Fig.1. A high-resolution (1996×1996 pixels) color CCD camera is set on the central pillar and directed downward to the stage. Every pixel in a image has three 16384 level (14 bit expression) values for R, G and B. The image plane (CCD plane) is adjusted parallel to the stage. (Note that images shown in this manuscript have smaller size and lower resolution because of the restriction caused by document file size, but full size images are used in our study in usual.) Synchronous flashlights are set to the top of slant pillars in the left side and right side. The coordinates are defined as Fig.2. The origin of camera coordinates is located at the center of the lens. Image plane is parallel to the stage. The origin of image coordinates is located on the ***Z*** axis. In general, surface of spread pages forms curved shape swelling from the central bounded valley-like part. In the image of spread page taken by camera in Fig.1, page surface is not depicted as exact rectangular region but bend rectangular region which have swollen top and bottom edge lines. The degree of swelling of the top line in the image has relevance to the 3-D page shape. If information about 3-D page shape is obtained, page image can be adjusted by geometrical compensation. The relation between 3-D point on the page surface and its projected corresponding point in the image is described as

$$x = f\frac{X}{Z} \qquad (1)$$

$$y = f\frac{Y}{Z} \qquad (2)$$

These are the basics of perspective transformation and these mean that the 2-D coordinates (***x, y***) in image and 3-D coordinates (***X, Y, Z***) on the subject are in proportion of focal length *f* and reciprocal of 3-D depth *Z*. Therefore we prepare depth axis ***z*** on

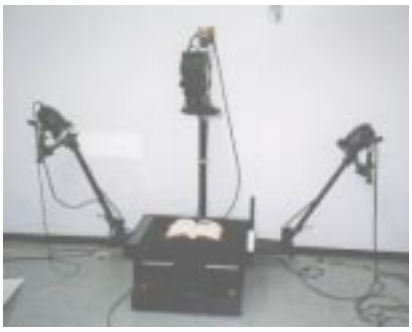


Figure 1. The image input device

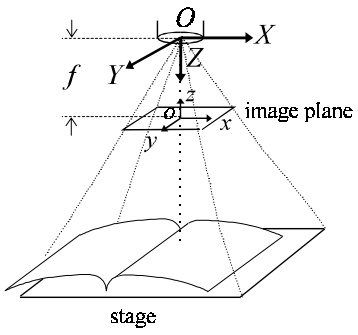


Figure 2. The coordinates definitions

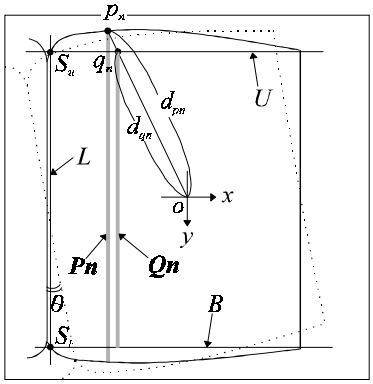


Figure 3. Illustration of a page image

image coordinates in order to treat the assumed 3-D height on image plane. After this, the adjustment method is discussed only on image plane using coordinates of (***x, y, z***).

The area drawn with dotted line in Fig.3 is an example of obtained page area in an image and the area drawn with solid thick line is the result of rotational transformation with angle -θ. By this transformation, the line on the bottom of the central valley of spread pages is arranged to be parallel to ***y*** axis. S_u is set on the top line of right-hand page area near the bottom of the central valley. L is a straight line through S_u and parallel to ***y*** axis. S_l is the cross point of L and the bottom line of right-hand page area.

The adjustment process consists of two parts. In the first part, vertically swelling area of page in the image caused by finite focus length of the camera is adjusted and 3-D shape information of page surface is calculated. In the second part, the view if the 3-D bend shape of the page is unbent to flat shape is obtained by horizontal geometrical transformation using 3-D information of page surface.

When the focus length f is infinite, even if the page has bend shape, the top and bottom edge lines lie on straight line U and B respectively in Fig.3 and the page is depicted as a exact rectangle area in the image. On the other hand, if a point p_n on the top line of the page has the same z with the point S_u, it will be projected on U in the image. p_n on the top line on the page figure should be moved to q_n when infinite focus length is assumed and under the condition that the page shape has the same z along with the vertical direction, the vertical pixel-sequence $\boldsymbol{P_n}$ will be remapped to $\boldsymbol{Q_n}$. When remappings of all the $\boldsymbol{P_n}$ are performed, adjusted image with assumption of finite focus length is obtained. The 3-D information of the page, in other words height information (h_n) of each q_n is calculated from d_{pn}, d_{qn} and f.

$$h_n = f\frac{(d_{pn} - d_{qn})}{d_{pn}} = f\left(1 - \frac{d_{qn}}{d_{pn}}\right) \qquad (3)$$

Where d_{pn} and d_{qn} are the distances between ***o*** and p_n, ***o*** and q_n respectively. The 3-D positional relationship is shown in Fig.4. In the second step, using the height information h_n of each q_n, pixel-sequence ***Qn***s are horizontally shifted and remapped on appropriate position in the image of flat page area. Thick bend line in Fig.5 shows a example of side view of the page surface. In order to get the shift distance for ***Qn***, each horizontal remapping distance l_n between neighboring calculation points (q_n and q_{n+1}) are calculated by linear approximation. In the remapping process, result value of each remapped pixel is calculated by linear approximation using values of nearest two points of object image in any case.

The top and bottom edge lines of the page in the image are obtained with simple method because the contrast between page area and background is strong. Top and bottom edge points of the page are detected by scanning the image vertically from top end and bottom end to check the transition of the pixel value is larger than the threshold. By chasing the edge points point by point, top and bottom lines are obtained. The point with maximum curvature on the

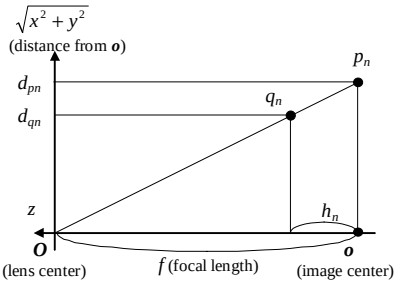


Figure 4. Relationship between p_n and q_n

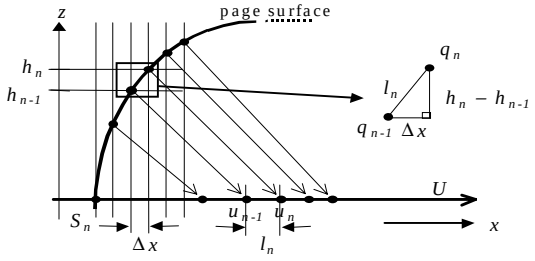


Figure 5. Mapping onto U

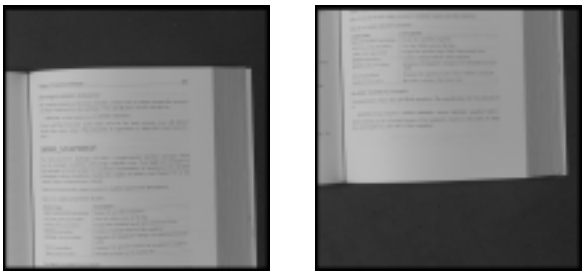
top and bottom lines are defined to be the top and bottom end of the bottom line of the valley-like part of the spread page area. If the obtained image mainly contains left-hand page area, the image is rotated with 180 degree beforehand.

4.2. Adjustment for Partly Photographed Images before Join Them Together

One of the solutions for requirement of high resolution image is that some partly photographed images are joined together in order to make an image of larger size. But the adjustment method mentioned in the previous section could not be applied to partly photographed image of a page if the top or bottom edge of the page is not depicted in the image because it uses information of curvature of page's top or bottom edge. In addition, if 3-D shape of joint area can be obtained and used in adjustment, more precise compensation of swell of page surface near the joint area can be performed and result image of joint process will have higher quality. For such case, 3-D page surface is obtained with neighboring two partial images of a page using stereo principle. When stereo method is applied to obtain 3-D information, corresponding points in two images of different view must be extracted. In our method, the pairs of corresponding points are extracted by matching of characters in overlapping area in neighboring two partial images. Fig.6 shows an example of partial images of a page. Though these images include top or bottom edge and number of partial images is only two, the condition is for the basic study of adjustment method. The stage in Fig.2 can be slid parallel with ***x*** and ***y*** axis, and partial images such as Fig.6 can easily be photographed. Magnified overlapped area of the images in Fig.6 are shown in Fig.7. Page view of the bottom area of upper partial image(a) and the top area of lower partial image(b) swell in the opposite direction. Then the degree of swell of page surface can be calculated by applying stereo method and 3-D page surface is obtained.

At first, characters in overlapped area are binarized and labeled along each text line in each partial image. Fig.8 shows example of labeled character. Then the feature matching of characters in each line is performed and one-to-one correspondence of each character is obtained. This matching is performed line by line for all the lines in overlapped area.

Each dot in Fig.9 is 3-D information of the page surface photographed in Fig.8 calculated using a pair of location parameter of the center of corresponding characters in each partial image. The continuous shape is estimated by 4-D polynomial approximation. After the 3-D shape of page surface is obtained, geometrical compensation by pixel value remapping, which is nearly the same process used for a whole page view in an image presented in previous section, is performed to obtain adjusted images ready to be joined together. The way of geometrical compensation of perspective projection and the way of pixel value remapping are similar to previous case of whole page depicted in an image. Fig.10 is the result of the adjustment of areas shown in Fig.7. This image is made by overlaying two areas of image using semitransparent mode in photo-retouch software, and two areas seem to perfectly overlap each other.



(a) Upper partial image (b) Lower partial image

Figure 6. Partly photographed page images

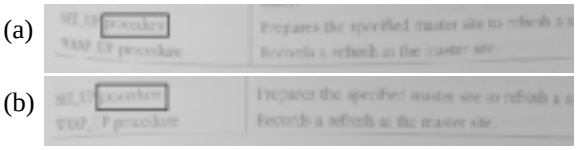


Figure 7. Overlapped area in Fig.6

(a) (b)

Figure 8. Labeled characters

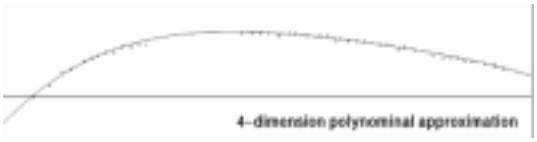
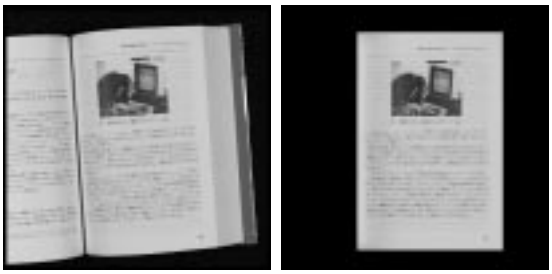


Figure 9. 3-D information of the page surface

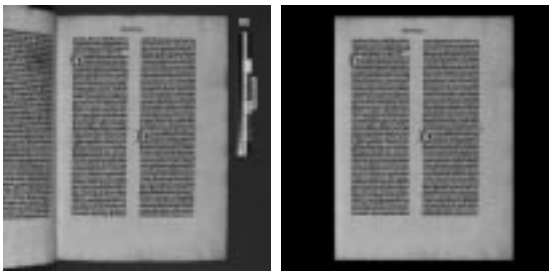
Figure 10. Result of adjustment

5. Experimental Results

A page image of a contemporary book obtained by the device shown in Fig.1 is shown in Fig.11(a). Fig.11(b) is the result of adjustment of Fig.11(a). Magnified image piece of the valley-like part in the page is also shown in (a) and (b). In (b), shape of



(a) A book : input (b) A book : result



(c) Gutenberg : input (d) Gutenberg : result

Figure 11. Input images and results of the adjustment

characters are compensated well. Fig.11(c) is a page image of the Gutenberg Bible and Fig.11(d) is the result of adjustment. In the example of contemporary book (Fig.11 (a) and (b)), as the surface of the object book satisfies assumed conditions in our method, good adjustment result could be obtained.

However, in the example of rare book (Fig.11 (c) and (d)), there are a few subtle unnatural contortion found in the area of printed letters. This is because the fine undulation on the page surface made by long time preservation under the changes of humidity. We are now working to cope with this special condition which rare books have. In the result images, there are shades on the left-hand side because we do not yet consider the lighting effect in our adjustment method.

Fig.12 is example of partly photographed rare book image in two parts, and Fig.13 is the joined image of result images of our adjustment method.

We are also working to develop a method to remove the shade in the results using 3-D information that is already obtained in first step in our present method.

6. Conclusion

In this paper we showed the outline of the HUMI project which is envisioning the research oriented digital library, and gave examples of the problems and requirements that are found in the activity the HUMI Project. Then we presented an image adjustment method to solve one of those problems and showed results of the adjustment. After this, we

(a) Upper partial image

(b) Lower partial image

(c) Image of jointed two adjusted images

Figure 12. Partial images and jointed image

are going to introduce pixel value conversion to reduce the shade in page image into this adjustment method.

Our goal for the present is to prepare the special method for making digital archives of rare books by solving and satisfying all the problems and requirements mentioned in Sec.3 as examples, and then complete the digital archiving of the objects held in Keio University library.

Questions and suggestions to us, as the people in the scene of studying rare books, are welcome.

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Digital image processing consists of the manipulation of images using digital computers. Its use has been increasing exponentially in the last decades. Its applications range from medicine to entertainment, passing by geological processing and remote sensing. Multimedia systems, one of the pillars of the modern information society, rely heavily on digital image processing.Â Therefore, it is necessary at first to give a brief introduction to digital image processing technology and related concepts. Digital image processing is to process images by computer. Digital image processing can be defined as subjecting a numerical representation of an object to a series of operations in order to obtain a desired result.