

A LARGE-SCALE PICTURE SCANNING SYSTEM BASED ON AUTOMATIC IMAGE DETECTION AND CONTENT CORRECTIONS

Kun-Wei Chou, Wen-Hsiang Tsai

Department of Computer & Information Science

National Chiao-Tung University

1001 Ta Hsueh Rd., Hsinchu, Taiwan 300, R.O.C.

Email:whtsai@cis.nctu.edu.tw

Abstract

Because the size of a picture in a library or museum is usually larger than the scanning area of a common scanner, a special-purpose scanning system for scanning large-scale pictures is proposed to establish a complete digital library or museum. First, a new approach to automatic image detection is proposed to scan a large-scale picture into several image pieces. Next, since the image pieces may be taken under various conditions of positioning, lighting, geometric distortion, perspective transformation, etc., a lot of problems arise in the process of integrating the image pieces to set up a complete image for the picture. In this study, we also propose a set of convenient and efficient algorithms to solve these problems. Good experimental results show the feasibility of the proposed system.

(KEYWORD: Image Detection, Illumination Correction, Geometric Distortion, Geometric Correction, Image Rectification, Image Registration, Color Correction)

1. Introduction

The picture in a library or museum appears in a variety of types, such as large-scale picture, thumbnail, miniature, etc. To establish a complete digital library or museum, it is necessary to develop an effective scheme to take digital images of pictures. Because the size of a picture might be larger than the scanning area of a common scanner, it is desired to study first the design of a special-purpose scanning system for scanning large-scale pictures. It is also desired to integrate the multiple image pieces taken from a large-scale picture into a single large image. Since image pieces may be taken under various conditions of positioning, lighting, perspective transformation, etc., a lot of problems in image integration arise. For this reason, in this study we will also try to design automatic, effective, and precise image correction and registration techniques based on the

use of image features.

Image rectification is often performed to correct images so that they would appear in a way similar to the case that the camera's line of sight is perpendicular to the object plane. Collins and Beveridge [1] made a significant step in this direction by showing that once the vanishing line of the plane is identified, the transformation [2] from the world to the image plane could be reduced to an affinity. Liebowitz and Zisserman [3] improved this result by using known metric information and the affinity can be reduced to a similarity.

We can remove geometric distortion from an image, at least approximately, if the image contains a known pattern, such as a regular grid [4, 5, 6, 7, 8, 9]. For this, first we have to find a transformation that maps grid points into their distorted positions. Then, the actual correction of the image data using this transformation is performed.

Over the years, a broad range of techniques to register two or more images has been developed [10]. Image registration techniques can be mainly divided into two categories: feature-based methods and featureless methods. In feature-based methods, it is assumed that feature correspondences between image pairs are available, and these correspondences are utilized to find transforms that register the image pairs [1, 11, 12]. On the other hand, featureless methods discover transforms for image registration by minimizing a sum of squared difference (SSD) function values that involve some parameters [13, 14, 15, 16, 17].

The proposed automatic large-scale picture scanning system has a computer-controlled architecture as shown in Figure 1.1. This motor-driven device is basically an upright X-Y table which has a rack on it and a motor controller. The rack can be controlled to move vertically and horizontally as desired by the scanning system. One CCD camera is

mounted on the rack with its focus on the large-scale picture that is in front of the camera. The camera is connected to an image frame grabber. The camera transmits NTSC color video signals to the image frame grabber. And the image frame grabber converts these signals into digital color images. Finally, a personal computer gets these color image data from the image frame grabber and performs necessary operations.

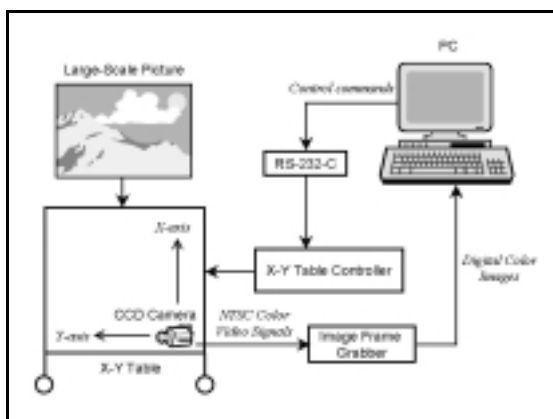


Figure 1.1 : Configuration of the proposed scanning system.

A flowchart of the proposed system is shown in Figure 1.2. First, some parameters should be calibrated in advance for later use in various image correction processes. Then, three main stages for scanning a large-scale picture start.

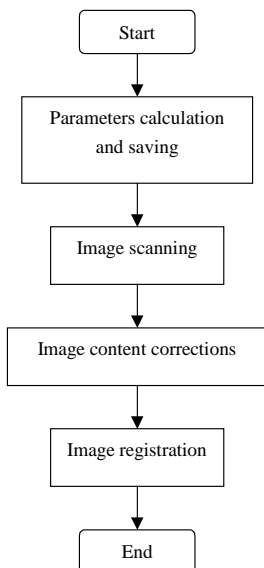


Figure 1.2 : Flowchart of proposed automatic scanning system for large-scale pictures.

2. Image Detection for Automatic Scanning

2.1. Proposed Approach to Detection of Image Border

As seen in Figure 2.1, the image border contains image

outlines and image corners. The useful information of the image border can aid the system in the automatic scanning task.

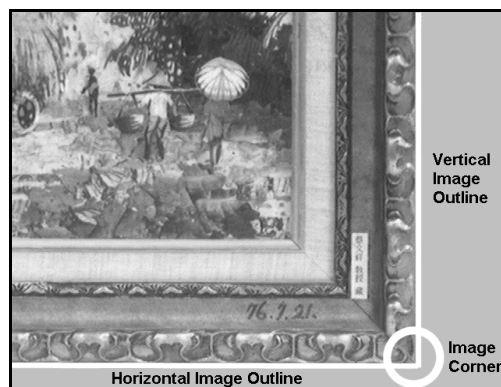


Figure 2.1: An example of image outlines and the image corner.

The left, right, top, and bottom outlines are concerned in this study. We describe how to detect the right image outline in the following. First, the Sobel operator is applied to the image to get the edge pixels and the gray levels of the edge pixels are changed to 255. Then, A simple scanning from the top row to the bottom one is applied to the resulting edge pixels. The scanning starts from the right of a row and proceeds leftward until it finds a pixel whose gray level is 255. Finally, the least-square-error line fitting method is used to create the desired right image outline using the detected pixels as input. The right image outline detection result is shown in Figure 2.2. The remaining types of image outlines can be detected with similar operations.

Because the outer shape of a large-scale picture is usually rectangular, it has four image corners. An image corner will be produced when two adjacent and perpendicular image outlines meet somewhere in the image. It can be figured out that when one of the end points of a detected



Figure 2.2: Right image outline detection results. (Note that the white line is the desired right image outline.)

image outline is inside the image (i.e., at a distance of at least several pixels from the image boundary), there will exist an image corner. That is, it is not necessary to calculate the actual location of the image corner.

2.2. Algorithm for Automatic Scanning

The proposed automatic scanning algorithm is based on the above approach. The system starts the scanning process from the origin of the X-Y table which is located at the lower-right corner as seen from behind it. A flowchart of the proposed algorithm for automatic scanning is shown in Figure 2.3. It starts with the capture of a color image of the picture using the camera. Then, it performs image processing to detect image outlines and image corners. If the result says that the image contains part of the picture, the system saves this image. Otherwise, the system calculates a new location of the CCD camera and sends this location as a control command to the X-Y table controller to execute proper movement. When the input image is saved, the system will determine whether it has found four image corners according to the results from the detection of the image border. If the answer is yes, the scanning stage is finished. Otherwise, the system repeats the same steps of the proposed automatic scanning algorithm.

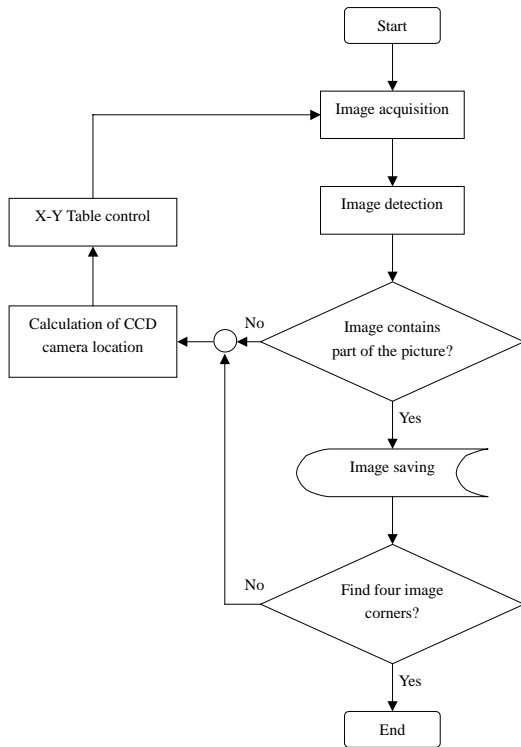


Figure 2.3: Flowchart of proposed algorithm for automatic scanning.

3. Illumination Correction for Lighting Variation

3.1. Computation of Coefficients for Illumination Correction

We paste a white paper that is larger than the picture on the wall where pictures to be scanned will be hanged later. We then take images of the white paper by the camera at all possible locations of the X-Y table close to which the image pieces of the picture will be taken later. To correct nonuniform illumination, we want all image pieces of the white paper have the same color values. The white paper is chosen because white color contains equal parts of red, green, and blue color values. However, in reality, these three parts differ because of the illumination and the spectral sensitivity of the camera. We choose the central image piece of the white paper and calculate the color values R_{CW} , G_{CW} , and B_{CW} to represent the color values of the central region of the image piece by the following equation:

$$\begin{aligned}
 R_{CW} &= \frac{\sum_{i=1}^{N \times N} (R_i + G_i + B_i)}{3 \times N \times N} \\
 G_{CW} &= \frac{\sum_{i=1}^{N \times N} (R_i + G_i + B_i)}{3 \times N \times N} \\
 B_{CW} &= \frac{\sum_{i=1}^{N \times N} (R_i + G_i + B_i)}{3 \times N \times N}
 \end{aligned} \tag{3.1}$$

where $N \times N$ is the size of the region and R_i , G_i , and B_i are the color values of each pixel in the region. Then, we divide R_{CW} , G_{CW} , and B_{CW} by each corresponding color value R_j , G_j and B_j of the pixel j in the image piece i , respectively, and perform the color calibration process for every pixel in each image pieces of the white paper. The quotients Q_{Rij} , Q_{Gij} , and Q_{Bij} are wanted coefficients for illumination correction. They are used to correct the illumination of the images which are acquired in the same conditions as the reference white paper.

3.2. Process of Illumination Correction

For each image piece of a large-scale picture, the calculated coefficients of the location nearest to the location where the image piece was taken are used to correct the illumination of the image piece. We take the products of the values of Q_{Rij} , Q_{Gij} , and Q_{Bij} and each corresponding color value R_j , G_j and B_j of the pixel j in the image piece i , respectively, as the corrected color values R'_j , G'_j , and B'_j for pixel j . Finally, we multiply some weight value w to the corrected color values to obtain a lighter or darker result.

4. Geometric Distortion Correction

The geometric distortion correction operations are done piecewisely in this study, by taking a few of the grid points and solving the coefficients of a transformation of some given form that takes the corrected coordinates of these points into their distorted coordinates. Each block in the rectilinear grid image can be corrected by the distortion model. The procedure of the geometric correction is presented in the following.

Suppose that an image f with pixel coordinates (x, y) undergoes geometric distortion to produce an image g with coordinates (x', y') . Our distortion model simply considers each block in the grid to be transformed by the following equation [6]:

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} c_1 & c_2 & c_3 & c_4 \\ c_5 & c_6 & c_7 & c_8 \end{pmatrix} \begin{pmatrix} x \\ y \\ xy \\ 1 \end{pmatrix} \quad (4.1)$$

where c_1, \dots, c_8 are the coefficients of the transformation matrix. Its corresponding four grid points can solve the coefficients for each block. The coefficients constitute the model that can be used to transform all pixels within the quadrilateral region characterized by the cross points. Then, the corrected pixels are assigned intensity by bilinear interpolation method.

5. Image Rectification

To achieve image rectification, we can transform the normal vector of the tilted plane into the direction of the optical axis of the camera. So the system should compute the normal vector of the tilted plane and then utilizes the computed normal vector to calculate a transformation to rectify the image. To find the normal vector of the tilted plane, we design a stair mark, as shown in Figure 5.1, and paste it on the wall where pictures to be scanned will be hanged on. The shape of the designed mark facilitates the subsequent operations of image processing.

As shown in Figure 5.1, two sets of mutually orthogonal parallel lines, denoted as line sets A and B , respectively, are seen to exist on the designed mark. Each line in line set A is perpendicular to each in B . As well known, the image lines in a set of 3D parallel lines intersect at a vanishing point on the image plane. This important property indicates that the vanishing point $v=(u_\infty, v_\infty)^T$ can be used to derive the 3D

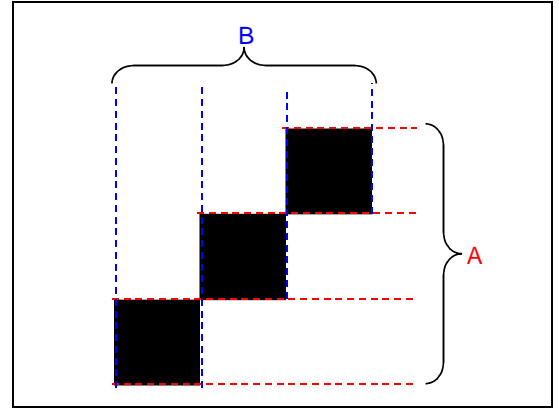


Figure 5.1: Illustration of the designed mark.

orientation $\mathbf{d}=(d_1, d_2, d_3)^T$ of the corresponding set of parallel lines.

$$(d_1, d_2, d_3)^T = \frac{1}{\sqrt{u_\infty^2 + v_\infty^2 + f^2}} (u_\infty, v_\infty, f)^T \quad (5.1)$$

where f is the focal length of the camera. By using Eq. (5.1), the unit direction of the two line sets can be calculated, denoted as \mathbf{d}_A and \mathbf{d}_B , respectively. After \mathbf{d}_A and \mathbf{d}_B are computed, the unit plane normal vector \mathbf{d}_z in the CCS is calculated as the cross product of \mathbf{d}_A and \mathbf{d}_B .

To bring $\mathbf{d}_z=(a, b, c)$ into coincidence with $\mathbf{d}_z=(0, 0, 1)^T$ requires a rotation of angle $\omega = \cos^{-1}(\mathbf{d}_z' \cdot \mathbf{d}_z)$ with respect to the axis $\mathbf{n}=\mathbf{d}_z \times \mathbf{d}_z'$. The effect of this camera rotation on the image can be simulated by an invertible projective transformation in the image plane [2]. The transformation is as follows:

$$(x, y, z)^T = \begin{pmatrix} E & F & a \\ F & G & b \\ -a & -b & c \end{pmatrix}^{-1} (x', y', f)^T \quad (5.2)$$

where $E = \frac{a^2c + b^2}{a^2 + b^2}$, $F = \frac{ab(c-1)}{a^2 + b^2}$, $G = \frac{a^2 + b^2c}{a^2 + b^2}$, $(x', y', f)^T$ is the original point in the CCS, and $(x, y, z)^T$ is the rectified point in the CCS.

The proposed image rectification procedure uses the transformation matrix calculated above to correct all image pieces of the picture. It then assigns intensity to corrected pixels by bilinear interpolation method.

6. Image Registration

6.1. Registration from Image Pairs

Figure 6.1 shows a flowchart of the proposed approach for image registration. The first step is to take two neighboring corrected images as input. The second step is to

perform image processing techniques on the basis image (the image to be registered) to select 10 templates. The third step is to match the selected templates with the corresponding templates in the target image (the image to be registered with the basis image) by a template-matching method. The fourth step is to find two best matching pairs of the basis and target images by some criteria. The fifth step is to register the two images. The sixth step is to save the registration result as an image file.

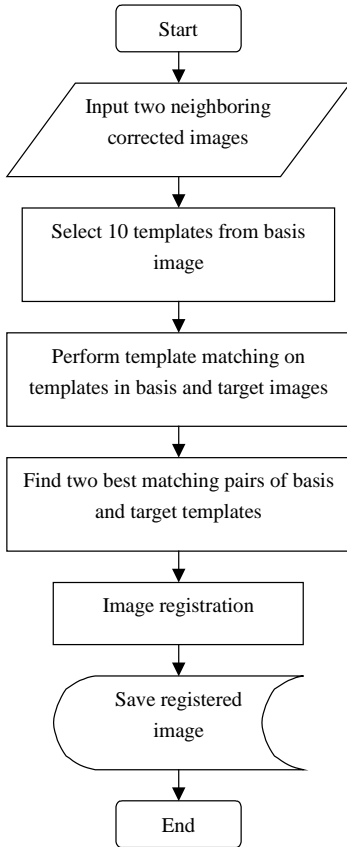


Figure 6.1: Flowchart of proposed image registration approach.

6.2. Overall Registration for Multiple Images

The proposed algorithm to register all images of a large-scale picture is based on the local registration method mentioned above. Because all images of the picture are taken with the help of the X-Y table, we know their corresponding positions of the mounted camera. The positions of the camera on the X-Y table can be labeled as C_{ij} , $i=1, 2, \dots, m, j=1, 2, \dots, n$, where m is the number of the rows and n is the number of images in each row. The labels are shown in Figure 6.2. Because the system employs the automatic scanning algorithm mentioned in Section 2.2 to take all images of the picture, the values of m and n can be known. The symbol R_i means the current registered image

of the i th row. The detailed algorithm is described as follows.

C_{m1}	...	C_{m2}	C_{m1}
$C_{(m-1)n}$...	$C_{(m-1)2}$	$C_{(m-1)1}$
⋮			
C_{2n}	...	C_{22}	C_{21}
C_{1n}	...	C_{12}	C_{11}

Figure 6.2: Labels of all positions of the mounted camera in the X-Y table.

Algorithm 6.1: Overall registration for all images of a large-scale picture.

Steps.

1. Set the image at C_{11} to be R_1 .
2. Set i to be 1 and j to be 2.
3. Register the basis image R_i with the target one C_{ij} . Let the resulting image be R_i .
4. If j is smaller than n , increase j by one and then go to Step 3.
5. If i is smaller than m , increase i by one and set j to be 1. Otherwise, go to Step 8.
6. Set the image at C_{ij} to be R_i , increase j by one, and then go to Step 3.
7. Set i to be 1.
8. If i is smaller than m , register the basis image R_i with the target one $R_{(i+1)}$. Let the resulting image be R_i . Otherwise, go to Step 10.
9. Increase i by one and go to Step 8.
10. Stop.

7. Color Correction

In this study, we propose a color correction method based on a linear interpolation technique. We call the region around the stitching line a transition area. For each transition area, we first define the weights of the basis image to decrease from 1.0 to 0.0 and the weights of the target image to increase from 0.0 to 1.0. The intensity of a pixel in the transition area is taken in this study to be a weighted sum of the intensity values of the two pixels from the basis and the target images. The intensity of a pixel in the transition area

can be written as

$$I_s(x, y) = I_B(x_B, y_B) \times (1 - \alpha) + I_T(x_T, y_T) \times \alpha \quad (7.1)$$

where I_s is the intensity of the resulting image of the registration at the position (x, y) of the transition area, I_B is the intensity of the basis image at the position (x_B, y_B) and it will locate at (x, y) after the registration, I_T is the intensity of the target image at the position (x_T, y_T) and it will locate at (x, y) after the registration, and α is the defined weight whose value is increased from 0.0 to 1.0.

8. Experimental Results

Several large-scale pictures were tested by our system. Each image piece of the picture acquired from the CCD camera has 640×480 pixels and 24 bits of intensity per pixel. The proposed automatic scanning system was implemented on a Pentium-III-450 PC and the software was developed by the use of the Microsoft VC++ 6.0. A window-based interface was designed to increase users friendliness.

The registration results of the test pictures are shown in Figure 8.1. Figure (a) in each of the figures shows the scanned image pieces of the picture, (b) shows the results of the corrections, and (c) shows the results of the registration.

Our experimental results prove that the image pieces of a large-scale picture can be scanned, corrected, and registered quite well by the proposed system. The proposed system is so feasible for real applications in digital libraries and museums.

9. Discussions

In the process of our research, some interesting issues arise. It is worth to discuss them as follows.

In the phase of automatic image detection for scanning large-scale pictures, the proposed automatic scanning algorithm can save time by scanning the picture in the “zigzag order”. But this process will fail if the outer shape of the picture is not rectangular or the hanged picture is severely skewed. For a successful scanning of the picture, we have to solve these problems in the future.

In the phase of corrections of image contents, our geometric distortion model is inapplicable if the image plane is not parallel to the rectilinear grid pattern. In such cases, other methods of geometric distortion correction should be proposed to solve the problem. Next, the proposed image rectification method utilizes the mutually orthogonal or

parallel properties of the lines of the designed mark and only computation of some analytic formulas is needed, which speeds up the estimation process of the plane normal. Also, the proposed illumination correction method is simple and it requires no estimation of the technical characteristics of the camera, the lighting source, and the reflectivity properties of the object.

In the phase of registration of all image pieces of the picture, an automatic registration approach is favored that requires no human involvement. The proposed system can register all image pieces of the picture automatically and precisely.

10. Conclusions

An automatic scanning system for scanning large-scale pictures has been successfully implemented. Achievements in three major phases of the system operations are summarized as follows.

In the phase of automatic image detection for scanning large-scale pictures, an automatic scanning algorithm has been proposed. The algorithm is used to scan the entire large-scale picture. This phase is the basis of the following phases.

In the phase of corrections of image contents, methods for geometric distortion correction, image rectification, illumination correction, and color correction have been proposed. These methods are used to correct the contents of all scanned image pieces to improve the quality of the image pieces.

In the phase of registration of all image pieces of a picture, an automatic and fast registration approach has been proposed. The proposed registration approach can register all image pieces of a large-scale picture to form a complete image of the picture automatically and precisely.

In summary, the goals of the large-scale picture scanning system have been achieved. The experimental results have revealed the feasibility of the above proposed system.

11. References

- [1] R. T. Collins and J. R. Beveridge, “Matching perspective views of coplanar structures using projective unwarping and similarity matching,” *Proc. IEEE Conference on Computer Vision and Pattern Recognition*, pp. 240-245, New York City, USA, June

- 1993.
- [2] K. Kanatani, "Constraints on length and angle," *Computer Vision, Graphics, and Image Processing*, vol. 41, pp. 28-42, 1988.
- [3] D. Liebowitz and A. Zisserman, "Metric rectification for perspective images of planes," *Proc. IEEE Conference on Computer Vision and Pattern Recognition*, pp. 482-488, Santa Barbara, USA, June 1998.
- [4] A. Rosenfeld and A. C. Kak, *Digital Image Processing*, vol. 2, Academic Press, 1982.
- [5] D. A. Butler and P. K. Pierson, "A distortion-correction scheme for industrial machine-vision applications," *IEEE Transactions on Robotics and Automation*, vol. 7, No. 4, August 1991.
- [6] R. C. Gonzalez and R. E. Woods, *Digital Image Processing*, Addison-Wesley Publishing Company, U.S.A., 1993.
- [7] J. C. Russ, *The Image Processing Handbook*, 2 Ed, CRC Press, 1995.
- [8] J. C. A. Fernandes and M. J. O. Ferreira, "Fast correction of lens distortion for image applications," *Industrial Electronics, 1997. ISIE '97, Proceedings of the IEEE International Symposium on Volume: 2*, vol.2, pp. 708-712, Guimaraes, Portugal, 1997.
- [9] Y. C. Lin and C. S. Fuh, "Distortion correction for digital cameras," *Computer Graphics, Image Processing, and Vision, Proceedings. 1998 International Symposium*, pp. 396-401, Rio de Janeiro, Brazil, 1998.
- [10] L. G. Brown, "A survey of image registration techniques," *ACM Computing Surveys*, vol. 24, no. 4, pp. 327-373, Dec. 1992.
- [11] J. W. Hsieh, H. Y. M. Liao, and Y. P. Hung (1995/8). "Image registration using a new edge-based approach," *Proceedings of 1995 Conference on Computer Vision, Graphics and Image Processing*, Taoyuan, Taiwan, Republic of China, pp. 216-224.
- [12] W. H. Hsu, "Geometric Correction, Scene Registration, and Object Extraction for Digital Camera Image Analysis," *A Master Thesis, National Chiao Tung University*, June 1999.
- [13] R. Szeliski and J. Coughlan, "Hierarchical spline-based image registration," *IEEE Conference on Computer Vision and Pattern Recognition (CVPR '94)*, pp. 194-201, June 1994.
- [14] R. Szeliski, "Image mosaicing for tele-reality applications," *IEEE Workshop on Applications of Computer Vision*, IEEE Computer Society, pp. 44-53, Sarasota, Florida, Dec. 1994.
- [15] R. Szeliski and H. Y. Shum, "Creating full view panoramic image mosaics and environment maps," *Proceedings of SIGGRAPH 97*, pp. 251-258, 1997.
- [16] Y. Xiong and K. Turkowski, "Registration, calibration and blending in creating high quality panoramas," *IEEE Workshop on Applications of Computer Vision*, IEEE Computer Society, pp. 69-74, 1998.
- [17] Y. Gong, G. Proietti, and D. LaRose, "A robust image mosaicing technique capable of creating integrated panoramas," *1999 IEEE International Conference on Information Visualization*, pp. 24-29, 1999.
- [18] R. M. Haralick and L. G. Shapiro, *Computer and Robot Vision, Volume II*, Addison-Wesley, New York, 1993.
- [19] Z. F. Yang and W. H. Tsai, "Using parallel line information for vision-based landmark location estimation and an application to automatic helicopter landing," *Robotics and Computer-Integrated Manufacturing*, Vol. 14, pp.297-306, 1998.
- [20] W. Press and et al., *Numerical Recipes in C: The Art of Scientific Computing*. Cambridge, England: Cambridge University Press, 2 Ed., 1992.
- [21] G. Wolberg. *Digital Image Warping*. IEEE Computer Society Press, Los Alamitos, California, 1990.



Figure 8.1(a) : All scanned image pieces of the picture.



Figure 8.1(b) : The results after content corrections.



Figure 8.1(c) : The registration result.