

Texture Overlay onto Deformable Surface Using Geometric Transformation

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Abstract

We propose a system that overlays textures onto the arbitrary deformable surface of an object in real time using HMD. In this system, we select a book as the object and documents as the textures. Such overlaying of textures is achieved by rendering warped textures onto a surface which is projected onto an HMD image using some geometric transformations. We assume that the surface of an object consists of curved sub-surfaces which can be generated by a 2D geometric transformation, so that we can warp textures using the matrix of 2D geometric transformation. In order to deform textures fitly, we select the fittest transformation of 2D geometric transformations which we choose in this system. Since the system computes the transformation matrix in each frame, the texture can be adjusted to the surface in real time even though an observer with HMD moves, turns a page, or deforms a page. Therefore, using this system, the observer can read digitized documents as if he reads real books.

Key words: Augmented Reality, Texture Overlay, Deformable Surface, Geometric Transformation, HMD

1. Introduction

Recently, there are many projects that digitally archive cultural heritages [10, 4, 5] such as precious books, fine-arts handicrafts, etc. Such digital archiving does not only preserve the cultural heritages, but also broaden the way of using them. For example, those digitized contents can easily be used through the computer networks, so that the value of them as study materials can be grown up by combining them with database systems.

On the other hand, it is also important to display the digitized contents realistically. CRT and LCD displays are generally used for viewing such digitally archived contents, but the reality of the original objects are lost because such displays can only show 2D image information. In addition, most of the cultural heritages are designated not to be touched. Therefore, to make it possible to feel as though one is touching and seeing them must be interesting and gives them more importance as study materials.

The technology which integrates the information in the virtual world with that in the real world is called aug-

mented reality (AR), which attracts attention as a new means of information presentation [9, 1, 3]. There are several ways to realize the AR display such as a Head Mounted Display (HMD) or a video projector. Using HMD is the most popular way to present the virtual world.

There are researches which use a book as an AR interface. Billinghurst et al.[2] use a real book and shows virtual objects on it using HMD. Robinson et al.[7] presents the LivePaper system. It shows textures on papers using projector. These researches use books, and show virtual objects on the surface which has markers or their correspondents. They don't suppose, however, that the books are objects with a deformable shape.

In this paper, we propose a system to overlay textures onto a deformable surface of an object in real time using HMD. In the system, the deformable object, on which a digitized document image is overlaid as the texture, is a book surface.

The shape of a page deforms when an observer with HMD moves, the book is moved, or the page is deformed by the observer. Therefore the overlaid document image must be warped so that the image can be appeared as if the image is attached onto the surface of their corresponding pages.

We achieve such realistic display of textures by overlaying a warped texture onto an video-see-through HMD image. The warping of the image can be performed by using geometric transformation between texture image plane and the HMD image plane. We assume that the surface of an object consists of curved sub-surfaces. For example, an opened book has two curved sub-surfaces. In this paper, we propose two methods for deforming the texture according to the method of approximating the sub-surface.

One is to assume that the sub-surface is a curved surface. In this case, a nonlinear geometric transformation is used for warping the texture. The other is to assume that a curved sub-surface is the aggregate of many small quadrilateral regions. Then a homographic transformation is applied for generating warped texture of each divided region.

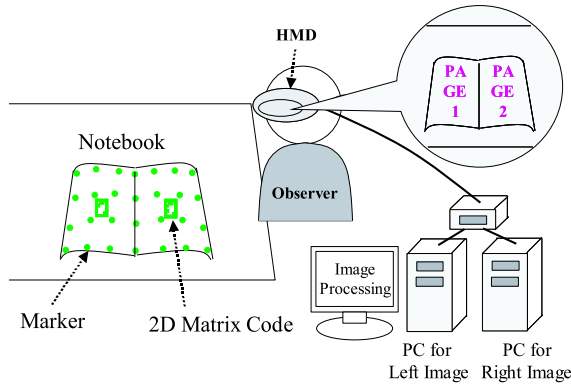


Fig. 1: The outline of a system.

We usually use the former, but when we can't determine the nonlinear geometric transformation, we use the latter.

For estimating the homographic transformation and the nonlinear geometric transformation, some pairs of corresponding points between the object surface and the image of HMD are required. In order to determine the corresponding points, markers must be printed on the surface of a page. The digital image corresponding to each page of the book must be loaded by recognizing 2D matrix code pattern printed on the page beforehand as well.

The advantage of the proposed system is that no 3D geometric information is required for the augmentation of the digital image onto the surface of the book. This is because we consider only 2D geometric transformations between the digital document and the HMD image. This feature also makes the computation simple, so that the system works in real time. Additionally, since the required devices in the system are only an HMD and one or two PCs, the system can easily be adapted to a wearable computer.

Using the system, an observer can read digitized documents as if he reads a real book. Moreover, this system is also applicable to the other objects by assuming that they are an object which has a deformable surface, so that the observer can not only see but also touch digital contents in the real world.

2. Outline of the System

Fig.1 shows the scheme of a texture overlay system. An observer with a video see-through HMD watches a book. The HMD has two CCD cameras which are attached at the front of the left and right eyes. The images captured by the HMD's cameras can be displayed inside the HMD, so that the observer can see the real scene captured by the HMD's cameras. The HMD images are also captured into the PCs for the processing. Digital documents are stored in the PCs, so that the texture of the document

can be overlaid onto the captured images.

Green colored markers are printed on the book for 2D transformation between the images and the digital document images. 2D matrix code patterns are also printed on the book. In this system, the data of 2D matrix code printed on a page represents page number and book ID number, so that we can select books and pages by hand in the real world.

3. The Method for Texture Overlay onto a Surface with a Deformable Shape

In this system, the texture overlaying is performed according to the following procedure. First, the markers are detected from the HMD images. The 2D matrix code pattern specifies the number of page and the book ID number that should be overlaid onto the object book. The positions of the markers detected in the HMD images determines the matrix of nonlinear geometric transformation between the book surface area in the HMD image and the digitized document image. The digitized document image is warped by the nonlinear geometric transformation, and then overlaid into the HMD image which is displayed inside the HMD.

We assume that the book surface consists of several curved sub-surfaces, and propose two methods for texture overlay according to method of approximating the surface. One is the method for using some nonlinear geometric transformations, and the other is the method for using homographies.

In this paper, we assume that the object with an arbitrary and deformable shape is a book. Since an opened book consists of two curved sub-surfaces, this method is applied to an HMD image twice per book.

The details of each process is the following.

3.1 Recognition of 2D matrix code

In this system, we overlay texture onto a deformable surface. In order to select the texture which should be overlaid onto a particular surface, the 2D matrix code printed on the surface have to be recognized.

Rekimoto[6] proposed a realtime object identification and registration method using 2D matrix code, but this 2D matrix code must be printed on a plane. We extend the 2D matrix code so that the system can recognize it even if it is printed on a curved surface.

3.1.1 Code Specification

The 2D matrix code is consist of 4×5 squared shape matrix with two colors, for example black and white, and a code frame which has the same width as a cell of the

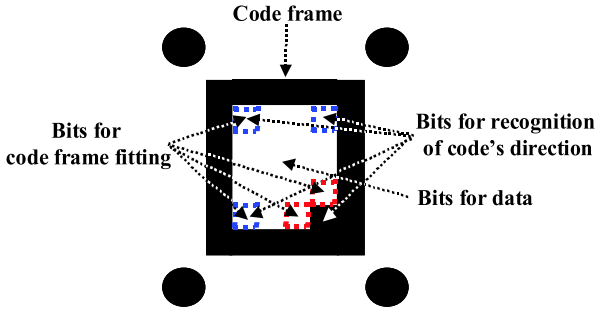


Fig. 2: Code specification

matrix. The matrix has the information of 20 bits. We use 4 bits for the recognition of the direction of a code, 4 bits, 2 bits of which are the direction bits, for the code frame fitting, and the other 14 bits for the data of the surface. Fig.2 shows the specification of the code.

3.1.2 Recognition Algorithm

The recognition algorithm of 2D matrix code will be explained in this section. First, we binarize an HMD image using the adequate threshold. Then, we label the connected regions of binary-1 pixels, and we count the number of binary-0 pixels inside each connected region. If the number of binary-0 pixels is over the adequate threshold, we take the region as a pick of a 2D matrix code and search for 4 markers which are closest to the region. Next, we calculate homography using the positions of the 4 markers, and transform the region into a square. Then, we find the code frame by searching binary-1 pixels in the square. Finally, if we can find the code frame and 6 cells of the matrix which we define as the cells for the code frame fitting and decision of the code's direction, we decide the region as a 2D matrix code and know the direction and the data. Fig.3 shows an example of the recognized 2D matrix code.

3.2 Detection of Markers

Since we overlay the digital document images onto the book surface with a deformable shape in the HMD image, we warp textures using 2D geometric transformation. The 2D geometric transformation is calculated by giving several pairs of corresponding points between the digital document and the book surface. Therefore we need to detect the positions of markers on the book surface in the HMD image.

First, we define the regions where we search for a marker as shown in Fig.4. We decide these regions from relationship between a 2D matrix code's position and markers' position. Then, we search for markers in each region. If there are more than 2 markers in a region, we choose the closest marker to the center of the region.

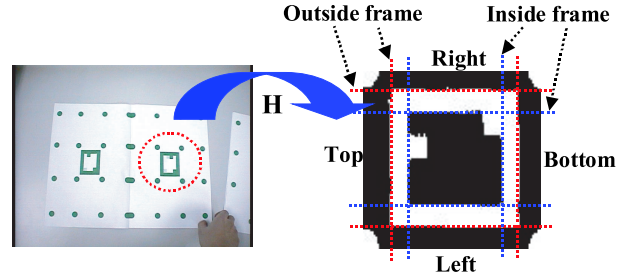


Fig. 3: Result of 2D matrix code recognition

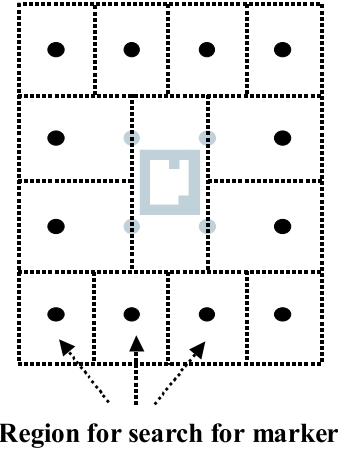


Fig. 4: Searching regions for the identification of the arrangement of markers

We show the result of the identification of the arrangement of markers using this method in Fig.5. Here, we number markers on each page according to the arrangement of markers, as shown in Fig.5(b).

3.3 Texture Overlay

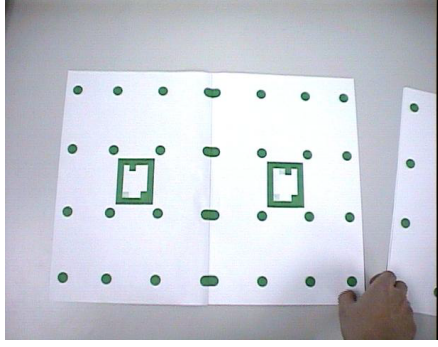
We propose two methods for texture overlay onto the book surface with a deformable shape. One is the method for assuming that the surface is a nonlinear curved surface. The other is the method for assuming that the surface is the aggregate of many small quadrilateral regions.

3.3.1 Geometric Transformation

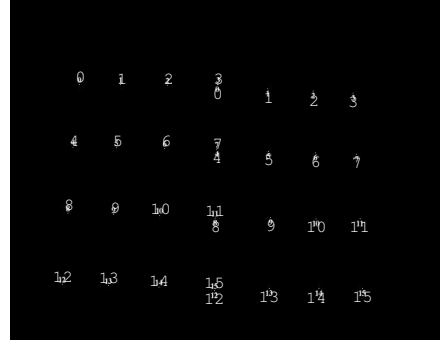
General 2D geometric transformation is described as the following equation(1).

$$\begin{aligned} \mathbf{x}_2 &= \sum_{i=1}^N \sum_{j=1}^M a_{ij} \mathbf{x}_1^i \mathbf{y}_1^j \\ \mathbf{y}_2 &= \sum_{i=1}^N \sum_{j=1}^M b_{ij} \mathbf{x}_1^i \mathbf{y}_1^j \end{aligned} \quad (1)$$

Here, \mathbf{x}_1 is a coordinate before being transformed and \mathbf{x}_2 is a transformed coordinate. This equation is also expressed by the following equation using matrices.



(a)original image



(b)numbering of markers

Fig. 5: The result of the identification of the arrangement of markers

$$d\tilde{\mathbf{M}}_2 = \mathbf{P}\tilde{\mathbf{M}}_1 \quad (2)$$

Especially we use following matrixes.

$$\tilde{\mathbf{M}}_2 = \begin{pmatrix} x_2 \\ y_2 \\ 1 \end{pmatrix} \quad \tilde{\mathbf{M}}_1 = \begin{pmatrix} x_1 \\ y_1 \\ 1 \end{pmatrix}$$

$$\mathbf{H} = \mathbf{P} = \begin{pmatrix} P_{00} & P_{01} & P_{02} \\ P_{10} & P_{11} & P_{12} \\ P_{20} & P_{21} & P_{22} \end{pmatrix} \quad (3)$$

$$\tilde{\mathbf{M}}_2 = \begin{pmatrix} x_2 \\ y_2 \\ 1 \end{pmatrix} \quad \tilde{\mathbf{M}}_1 = \begin{pmatrix} x_1^2 \\ y_1^2 \\ x_1 \\ y_1 \\ 1 \end{pmatrix}$$

$$\mathbf{P} = \begin{pmatrix} P_{00} & P_{01} & P_{02} & P_{03} & P_{04} \\ P_{10} & P_{11} & P_{12} & P_{13} & P_{14} \\ P_{20} & P_{21} & P_{22} & P_{23} & P_{24} \end{pmatrix} \quad (4)$$

$$\tilde{\mathbf{M}}_2 = \begin{pmatrix} x_2 \\ y_2 \\ 1 \end{pmatrix} \quad \tilde{\mathbf{M}}_1 = \begin{pmatrix} x_1^3 \\ y_1^3 \\ x_1 \\ y_1 \\ 1 \end{pmatrix}$$

$$\mathbf{P} = \begin{pmatrix} P_{00} & P_{01} & P_{02} & P_{03} & P_{04} \\ P_{10} & P_{11} & P_{12} & P_{13} & P_{14} \\ P_{20} & P_{21} & P_{22} & P_{23} & P_{24} \end{pmatrix} \quad (5)$$

The 3×3 matrix given by eq.(3) is called homography, and especially we describe this matrix as \mathbf{H} . In this paper, we call the 3×5 matrix given by eq.(4) the matrix of quadratic geometric transformation, and call the matrix given by eq.(5) the matrix of cubic geometric transformation. We can determine the homography from four or more corresponding points between two images and can determine the matrix of the two nonlinear geometric transformations from seven or more corresponding points.

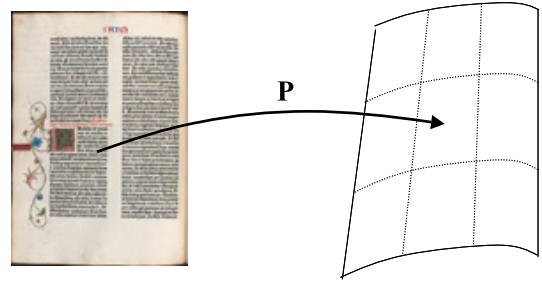


Fig. 6: Texture overlay using the matrix of nonlinear geometric transformation

3.3.2 Approximation of a Surface to a Curved Surface

We can assume that the arbitrary curved surface of the object is a nonlinear curved surface, and overlay a texture onto the curved surface. We can overlay the digital document image onto the surface by warping the digital document image using the nonlinear geometric transformation, as shown in eq.(4) or eq.(5). We need at least seven markers' positions to determine the matrix. We use either transformation of eq.(4) or eq.(5) which gives better approximation in each frame. Fig.6 shows the scheme of texture overlay using this method.

3.3.3 Division of a Curved Surface into Planes

In the case that the arbitrary curved surface of the object can be approximated by the aggregate of many planes, we divide the curved surface into 3×3 rectangular regions, and the digital document image into 3×3 rectangular regions. Then, we can overlay the digital document image onto the surface by deforming the divided image of each region using the homography between the region of the surface and its corresponding region of the texture, as shown in Fig.7. We need at least four markers' positions to determine the homography.

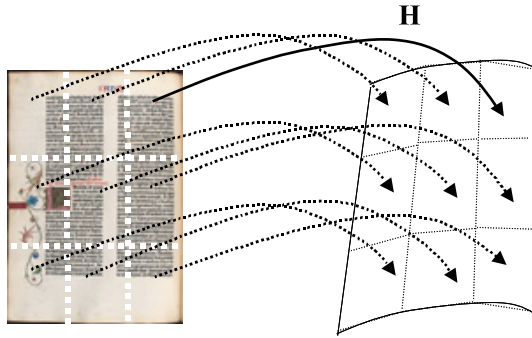


Fig. 7: Texture overlay using homography

4. Implementation and Evaluation

We performed the following experiments in order to show the validity of the system.

We use a stereo video see-through HMD made by CANON[8]. It is attached to two cameras and its optical axes of the imaging system are aligned with its optical axes of the display system in order to avoid special perception error. The two CCD cameras capture the real world and output a stereoscopic image. The size of an HMD image is 640×480 .

Images captured by this HMD are processed by two PCs. One is for left image and the other is for right image. The configuration of each PC is Intel Pentium4 Processor 2.8Ghz, 1024MB RAM, 64MB NVIDIA GeForce4 MX420 graphics card, IO-DATA GV-BCTV5/PCI capture card, and Redhat Linux7.3.

In Keio University, the HUMI project[10] group has a set of digitized images of the Gutenberg Bible which is known as the first printed book in the world, and the Conrad Gesner's Thierbuch which is known as natural history book. We use these images as the digital documents which are overlaid onto the book surface. The image size is 348×504 pixels. We show these images in Fig.8.

We use a A4-sized notebook as a sample of a book, on the pages of which markers are printed beforehand.

First, we compare two nonlinear geometric transformation as shown in eq.(4) and eq.(5). Fig.9(a) and Fig.10(a) is the result of texture overlay using eq.(4). Fig.9(b) and Fig.10(b) is the result of texture overlay using eq.(5). The texture is overlaid in Fig.9(a) fitter than in Fig.9(b). On the other hand, the texture is overlaid in Fig.10(b) fitter than in 10(a). So, we select fitter matrix in each frame.

Next, we compare two texture overlay methods which are described in sec.3.3.2 and sec.3.3.3. Fig.11(a) is a overlay image using the method for the approximation of the surface to a nonlinear curved surface, and Fig.11(b) is a

overlay image using the method for the division of the surface into planes. You can see the Fig.11(a) is a little smoother than Fig.11(b). When we transform the surface, the difference between these two images appears. However the method for the approximation of the surface to a nonlinear curved surface need more markers than the method for the division of the surface into planes.

Therefore we use the method for the approximation of the surface to a nonlinear curved surface in order to overlay textures, as long as more than seven markers are recognised. When we know less than seven and more than three markers' positions, we use the method for the division of the surface into planes. In the following experiments, we assume that we know more than six markers' positions.

Fig.12(a) and Fig.12(b) show a case that a notebook is turned upside down. The texture is overlaid adequately, because the arrangement of markers on the page is recognized.

Fig.13(a) and Fig.13(b) show a case that we turn a page. This result shows that the system recognize a 2D matrix code and know a page number.

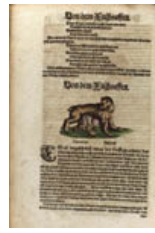
Fig.14(a) and Fig.14(b) show a case that the we see some books. The texture is overlaid adequately, which shows that the data of a book ID number in a 2D matrix code is recognized correctly.



(a)Bible page1



(b)Bible page2

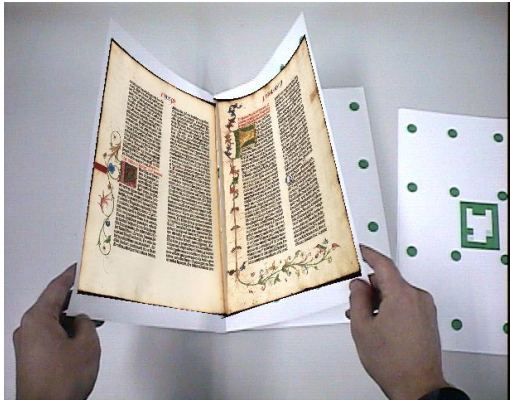


(c)Thierbuch page3

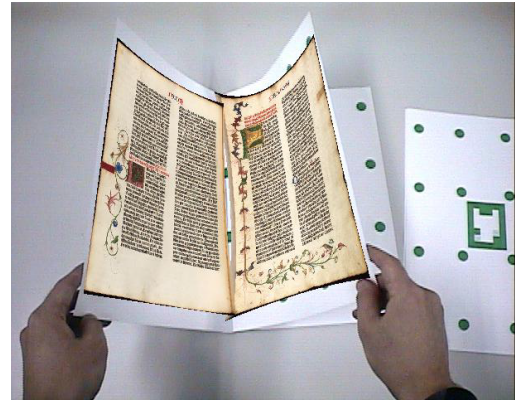


(d)Thierbuch page4

Fig. 8: Digitized images of the Gutenberg Bible and Conrad Gesner's Thierbuch



(a)overlay image using eq.(4)



(b)overlay image using eq.(5)

Fig. 9: Comparison between texture overlay image using eq.(4) and texture overlay image using eq.(5)



(a)overlay image using eq.(4)



(b)overlay image using eq.(5)

Fig. 10: Comparison between texture overlay image using eq.(4) and texture overlay image using eq.(5)

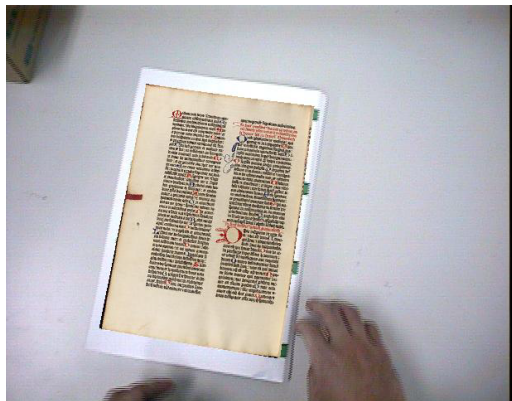


(a) overlay image using method for approximation of a surface to a curved surface

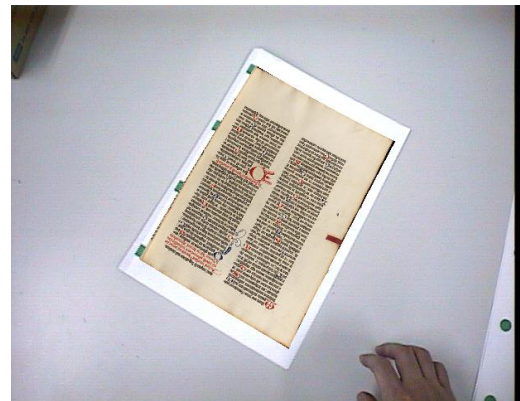


(b) overlay image using method for division of a surface

Fig. 11: Comparison between texture overlay image using the method for approximation of the surface to a nonlinear curved surface and texture overlay image using the method for division of the surface into planes



(a) original image



(b) overlay image

Fig. 12: A case that a book is turned upside down

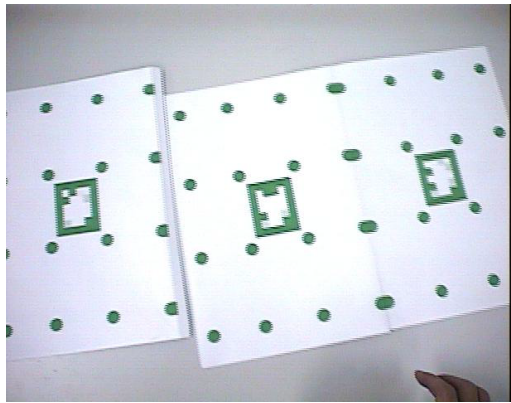


(a) page 1,2



(b) page 3,4

Fig. 13: A case that we turn a page



(a)original image



(b)overlay image

Fig. 14: A case that we see some books

5. Conclusion

In this paper, we proposed a system that overlay textures onto the surface of an object with a deformable shape. We select a book as the object, and digital documents as the textures. We proposed two methods for texture overlay. One is the method for approximating the surface as a nonlinear curved surface and using the matrix of a nonlinear geometric transformation. We use two nonlinear geometric transformations, and select fitter transformation in each frame. The other is the method for dividing the surface into planes and using homographies. In order to overlay the textures, the former method is preferred as long as more than seven markers are recognised. When this condition is not fulfilled, the latter is still available with more than three recognised markers. Moreover, we propose a 2D matrix code which is recognized even if it is printed on a curved surface.

We can make an observer feel as if he is reading a real book using the system. In the future, we will adapt the system to other objects and adapt more adequate geometric transformation in order to show more natural AR expression.

References

1. R.T.Azuma, "A survey of augmented reality", *Presence*, vol. 6, no. 4, pp. 355-385, 1997.
2. Mark Billinghurst, Hirokazu Kato, Ivan Poupyrev, "The MagicBook: a transitional AR interface", *Computers & Graphics* 25 (2001) 745-753
3. M. Billinghurst, I. Poupyrev, H. Kato, and R. May, "Mixed Realities in Shared Space: An Augmented Reality Interface for Collaborative Computing", *Proceedings of ICME 2000, IEEE*. pp. 1641-1644, 2000.
4. M. Levoy et.al., "The Digital Michelangelo Project: 3D Scanning of Large Statues", *Proc. SIGGRAPH 2000*, July 2000.
5. D. Miyazaki, T. Ooishi, T. Nishikawa, R. Sagawa, K. Nishino, T. Tomomatsu, Y. Takase, K. Ikeuchi,

"The Great Buddha Project: Modeling Cultural Heritage through Observation", *VSM2000 (6th international conference on virtual systems and multimedia)*, pp.138-145, Oct.2000.

6. Jun Rekimoto, "Matrix : A Realtime Object Identification and Registration Method for Augmented Reality", *APCHI'98*
7. John A. Robinson, Charles Robertoson, "The LivePaper system: augmenting paper on an enhanced tabletop", *Computer & Graphics* 25 (2001) 731-743
8. Akinari Takagi, Shoichi Yamazaki, Yoshihiro Saito, and Naosato Taniguchi, "Development of a Stereo Video See-through HMD for AR Systems", *ISAR2000*.
9. H. Tamura, H. Yamamoto, and A. Katayama, "Mixed reality: Future dreams seen at the border between real and virtual worlds", *Computer Graphics and Applications*, vol.21, no.6, pp.64-70, 2001.
10. <http://www.humi.keio.ac.jp/>