# Displaying Digital Documents on Real Paper Surface with Arbitrary Shape


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## Abstract

*In this paper, we propose a system that displays digital documents on real paper surface with arbitrary shape, so that the viewer can feel as if the digital document images are printed on the real paper surface. Such displaying of the digital documents is realized by rendering the document images on the arbitrary shaped surface via a projector. We apply a homography between a source image plane and a projector image plane to render the images on the surface. For adapting the arbitrary shape of the surface, we divide the shaped surface into many small rectangular regions, and generate warp image of each region by calculating this homography of the plane of each divided region. By projecting the warp image on the real surface, the image can be observed as if the image is printed on the surface. Since the system always compute the homography of each divided region, the image can be aligned onto the surface even the surface moves.*


## 1. Introduction

Recently, there are many projects that digitally archive cultural heritages which preserve or use as study materials and so on[2]. These works also needs realistic display of the digitized contents for convenient use. CRT and LCD displays are generally used for viewing, but the reality of the original objects are lost because they can only show 2D image information.

To solve this ploblem, we render the digital contents onto objects with arbitrary shape by general projectors but the distortion will arise according to the unevenness.

In this paper, we suppose that the digital contents are document images that are originally printed or wrote on papers, and consider projecting them onto a blank paper surface with arbitrary shape via a projector. For such projector-based display system, we propose the technique of generating the image which can be rendered without being distorted onto a curved surface by homography between the projector image plane and the object plane. For taking into account the shape of the surface, we compute the homography for each sub-region divided from the object surface. By using such homography-based method, we can avoid 3D calibration of the camera and the projector[1]. We build a system which captures the paper surface image online, and then automatically updates the projected document image by using PCs. This system makes it possible to render arbitrary images with a user as if it was the contents of an actual book.

## 2. Outline of Proposed System

Fig.1 shows the configuration of the proposed displaying system. The camera and the projector are installed over an opened book with blank papers on which the digital document images are projected. We need not know the geometrical relationship among them.

In this system, first, the lattice pattern projected by the projector onto to the book surface is captured by the camera, and used as markers for computing homography between the book surface and the projector image plane. Then, by warping the document image according to the homography and projecting onto the surface by the projector, we can observe it as if the image is printed onto the surface. By repeating a series of those processes and updating the warping of the projected image, the projected image can always be projected onto the surface correctly, even if the book surface moves and changes its shape.

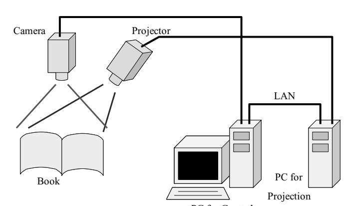


**Figure 1. The proposed system.**

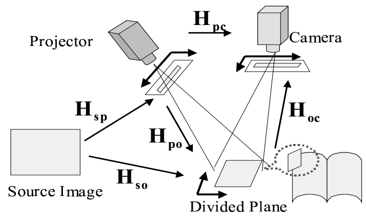


**Figure 2. The relation between a projector, a camera, and an object (divided) plane.**

**Figure 3. Projection of the document image of the Gutenberg Bible [2]. A user can look at the Gutenberg Bible with feeling which treats an actual book.**

## 3. Warping Transform

We describe the method for generating a warped image that can be projected onto the object surface.

### 3.1. Dividing object surface

Usually, the surface of a book has an arbitrary shaped surface. By regarding it as a set of a number of rectangular regions, we can consider homography between each divided plane. In this paper, the red markers are given as the vertices of the rectangles and extracted in an input image.

### 3.2. Estimating homographies

The projected image is also divided into a number of rectangular regions in the same way as the object surface is divided. Each divided sub-image is warped by the homography $\boldsymbol{H_{sp}}$ for warping the source image that is to be projected onto the object surface via the projector. For determining the homography $\boldsymbol{H_{sp}}$, we have to estimate the homography $\boldsymbol{H_{pc}}$ between the projector image plane and the camera image plane, the homography $\boldsymbol{H_{oc}}$ between the object surface plane and the camera image plane, and the homography $\boldsymbol{H_{so}}$ between source image plane and object surface plane(shown in Fig.2).

We can get $\boldsymbol{H_{pc}}$ by using correspondence of the feature point of the lattice pattern that is projected onto the object surface and $\boldsymbol{H_{oc}}$ by four adjacent points of the extarcted markers on the object surface in input image.

We can also get the homography $\boldsymbol{H_{so}}$ by the correspondence of each divided rectangular region with the source image, which is defined according to the part of source image should be projected onto the surface region.

Now we obtain the homography $\boldsymbol{H_{sp}}$ by the following equation :

$$\boldsymbol{H_{sp}} = \boldsymbol{H_{po}^{-1}} \boldsymbol{H_{so}}, \boldsymbol{H_{po}} = \boldsymbol{H_{oc}^{-1}} \boldsymbol{H_{pc}} \qquad (1)$$

### 3.3. Warping source image

Each sub-region is warped by the estimated $\boldsymbol{H_{sp}}$ for the region. Then the image to be projected is generated by compounding all the warped images. For reducing the compounding error that is caused by the approximation that each divided region is plane surface, the homography applied to each pixel in the source image is interpolated from the homographies on the adjacent sub regions.

## 4. Implementation

We conducted the following experiments. An example source image is 640×480-pixel image. We use a B4-sized notebook as an example of book surface and the surface is divided into sub regions of 4×8 rectangles. A lattice pattern of the 320×240-pixel with 10 pixels is projected for estimating the homographies. Fig.3 shows the source image and the appearance of the notebook with the warped image.

## 5. Conclusions

In this paper, we described the method for projecting a source image onto an arbitrary shaped surface by a projector. We divide the surface into a number of rectangular regions and compute homographies of each sub-region, then we warp the source image by them. We also built a system that a source image can be projected onto a notebook surface with arbitrary shape. This system enables it to project arbitrary digital documents as if it is printed on a real paper surface of a book.

## References

[1] R. Sukthankar, R. Stockton, M. Mullin, Exploiting Homography in Camera-Projector Systems, Proceedings, International Conference on Computer Vision, pp.247-253, 2001.

[2] http://www.humi.keio.ac.jp/

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