Virtual Display System Using Video Projector onto Real Object Surface

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Abstract

In this paper, we propose a virtual display system onto a real object surface using a video projector, so that the viewer can feel as if digital images are printed on the real surface with arbitrary shape. We apply a homography between the source digital image plane and the projector image plane to render the images on the object surface. For adapting not only the single planar but also the arbitrary shape of the surface, we divide the object surface into many small rectangular regions, and generate warped image of each region by calculating this homography of the plane of each divided region. By projecting the warped image on the real surface, the image can be observed as if the image is printed on it. In this system, the rendered image can be updated easily if the object surface moves and changes its shape, or refined when it is standing still. Our system consists of the uncalibrated camera and video projector connected to PC, and has the advantage of needing neither a prior setup nor other expensive equipments.

Key words: Texture Mapping, Camera, Video Projector, Homography, Arbitrary Shaped Surface, Calibration Free

1. Introduction

Recently, there are many projects that digitally archive cultural heritages such as precious books, fine-arts handicrafts, etc [4,5,12]. Such digital archiving does not only preserve the cultural heritages, but also broaden the way of using them. On the other hand, realistic display of the digitized contents is also important. CRT and LCD displays are generally used, but the reality of the original objects is lost because such displays can only show 2D image information.

For more realistic displaying of such digital information, the method that renders the saved contents onto white objects via a projector and recreate them are proposed [6,7,9]. Thereby, the reality is maintainable because the viewer can not only observe but also touch the digital contents in the real world. This method is also applicable to build a virtual museum by projecting various digital contents onto same real object.
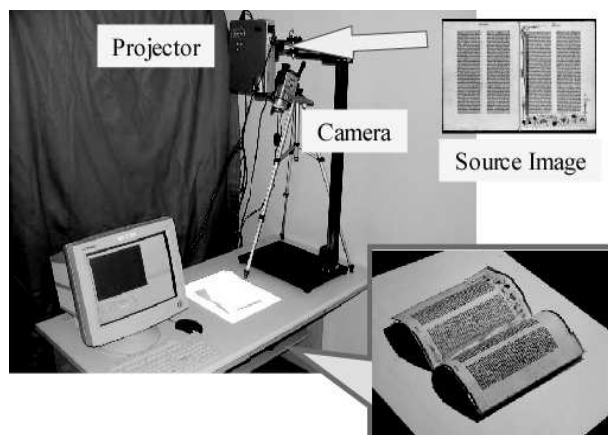

Fig. 1 The appearance of our virtual display system (left) and the result of projection (right). The user can view as if digital images are printed on the object book surface.

The technology, which integrates the information in the virtual world with the real world, is called "augmented reality (AR)", which attracts attention as a new means of information presentation [1]. One popular way to realize the AR display is a use of a wearable interface like a Head Mounted Display (HMD). Another way is using a projector, which has an advantage that we can observe the digital contents in more natural manner than with HMDs.

However, if we are going to render the digital contents onto objects with arbitrary shape by general projectors, distortion will arise according to the unevenness because such projector assumes only the plane screen as a target. Then, it is necessary to perform geometry registration between the rendered image and the object surface correctly.

In previous works [3,6,7], it is general method for geometry registration to measure the shape of a subject object via triangulation measurements with a calibrated camera and projector or the expensive equipment such a laser scanner, and match their 3D information and 2D information of projection images.

In this paper, we propose the technique of generating the image that can be rendered without being distorted onto
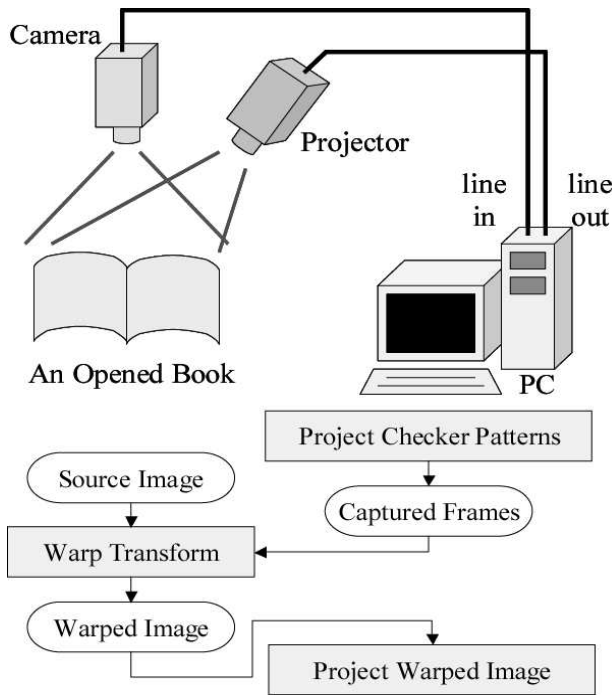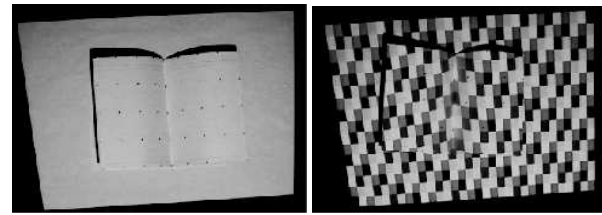
Fig. 3 Captured frames of the object surface on which the each pattern is projected.

NVIDIA's nView multi-display software and output both an application interface for CRT display and a rendering image for projector all at once.

Processing is performed as follows. First, for acquiring the status of the book surface, the white homogenous illumination is projected onto the book surface via the projector, and then a sequence of color-coded checker patterns is projected onto the book surface via the projector. Value (eight colors) in the sequence changes according to the position in the pattern, so by projecting n another patterns, the position in the pattern can be encoded by $3n$-bit. The camera captures all scenes of the book surface on which those patterns are projected. The camera image of projected white homogenous illumination (shown in Fig. 3 left) is used for detecting grid dots printed on the surface, which define sub-rectangular area that can be approximated to a planar area. The dot positions also determine homography between the book surface and the camera. From the camera images of the checker pattern projected sequence (shown in Fig. 3 right), the corner positions of the checker pattern are detected and used as markers for estimating homography between the book surface and the projector image plane. Then, a digital source image that should be rendered onto the object surface without distortion is generated by warped according to these homographies. By repeating a series of these processes, the rendered image can be updated even if the book surface moves and changes its shape.

In [2], we already proposed the basic concept of this system. In [2], however, we did not use the projection of the gray code pattern on the object, but just a simple grid pattern. Therefore, the system in [2] did not work online, and takes a few minutes for achieving correct projection on the object. In the system presented in this paper, we totally improve the system performance by projecting the colored gray code pattern for obtaining shape of object surface.

3. Warping Transform

3.1. Homography Geometry

Suppose that a plane A in 3D space is seen by two cameras C_1, C_2. All the points on this plane satisfy the relationship represented by the following equation between two images I_1, I_2.
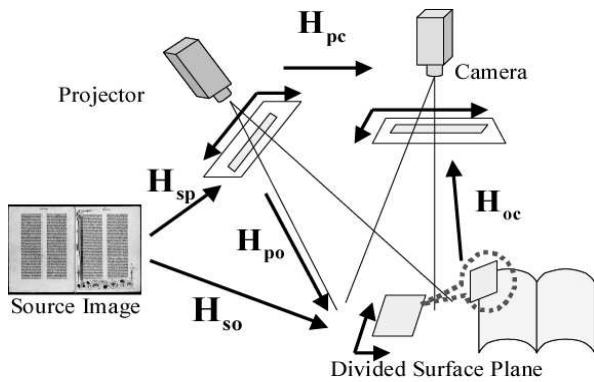

Fig. 2 System configuration (upper) and the flow of processing (lower).

a curved surface by using homography. We regard the object surface as a set of a number of small rectangular regions and by calculating homography between the projector image plane and the each divided region perform geometry registration at the time of rendering warped image. By using such homography-based method, we can avoid the use of all 3D information, so need not the special knowledge or the expensive equipment like the conventional method.

Here we consider digitally captured document images as the digital contents. Such digital documents are originally printed or wrote on papers. Although the paper is basically 2D plane, the shape of the paper surface changes when the viewer looks them in a real world. Therefore we consider projecting such digital document images onto a blank paper surface with arbitrary shape via a projector for integrating the real object with the digital contents. Fig. 1 shows our system appearance.

2. Outline of Proposed System

Fig. 2 shows the configuration of the proposed displaying system and the follow of processing in this system. A camera and a video projector are installed over an opened book with blank papers as an object surface. Our system avoids 3D calibration of them, so their positions and directions may be unknown. The video projector projects digital document images onto the object surface. The image of the camera provides status of the surface, such as the position, orientation, shape, etc., so that the projected images can be seen as if the images are attached on the surface. The camera and the projector are connected to same PC. We use

Fig. 4 The relation between each planar.

$$\lambda \tilde{p}_2 = H \tilde{p}_1 \tag{1}$$

Here, $\tilde{p}_1$ and $\tilde{p}_2$ are homogeneous coordinates of the corresponding points between I_1 and I_2. λ is scale factor. Matrix H is called homography and has a different value according to each plane in 3D space [11]. Homography is a 3×3 matrix and has 8 degrees of freedom, so we can determine it from four or more corresponding points between the two images.

There are some researches for projecting images onto an arbitrary plane without perspective distortion based on the theory of the homography. Raskar [8] proposed a self-correcting projector attached camera rigidly to form a stereo pair. In this method, correction of distortion of the image is performed by calculating homography between projector and screen using a calibrated camera and projector.

Sukthankar [10] proposed the more detailed method of determining homography in a camera-projector system. This method employs the technique of calculating homography for warping images from the source image to the correcting image is taken. Sukthankar's method is just for projecting images onto only a single plane with unknown position and pose, but our purpose is projecting onto a surface with arbitrary shape by applying it.

The surface of an object book usually has an arbitrary shaped surface, so we can't use homography which is planar geometry. Here by regarding it as a set of a number of rectangular regions, we can approximate each sub-region to plane, so that we can consider homography between each divided plane and the projector image plane.

3.2. Dividing Object Surface

In this paper, we divide the book surface into 32 of 4×8 rectangles. We place the red markers that represent the vertices of the rectangles. The markers are extracted in the camera image, which is projected white homogenous pattern (shown in Fig.3 left). The rectangle of four adjacent vertices is assumed as a plane segment.

3.3. Estimate 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 H_{sp} between the sub-image and the projection-image about its corresponding rectangular region of the object surface.

For determining H_{sp}, we consider other homographies H_{oc} between the object surface plane and the camera image plane, H_{pc} between the projector image plane and the camera image plane, and H_{so} between the source image plane and the object plane (shown in Fig. 4). These homographies are related by the following equation:

$$H_{po} = H_{oc}^{-1} H_{pc} \tag{2}$$

$$H_{sp} = H_{po}^{-1} H_{so} \tag{3}$$

By determining three matrices H_{pc}, H_{oc} and H_{so}, the warping matrix H_{sp} can be obtained.

We can get H_{oc} according to the fact that divided plane is a rectangular with previously known aspect ratio. Since the scale factor to represent the positions on the object surface can be cancelled in the later procedure, the aspect ratio of the rectangular on the object surface is sufficient to determine the homography H_{oc}. Thus, we suppose the position of four vertices of on the object surface with arbitrary scale according to the aspect ratio of the rectangular. In addition to that, four adjacent points of the markers on the object surface are extracted as feature points in the camera image of white homogenous projected pattern. The correspondence of the four points derives the homography H_{oc}.

We can also get H_{pc} by using correspondence of the corner points of the checker patterns that are projected onto the object surface. Each pattern consists of a set of the rectangle with eight colors. Value (which color the rectangle has) in the sequence changes according to the position in the pattern. The position in the pattern can be encoded by the sequence of eight colors (so that it has 3-byte information). Therefore, we can get the positions of the four vertices of the corner of the checker pattern from all the camera images of entire patterns. Fig. 4 right shows one of the input images on which the color-coded pattern is projected. By using these correspondences of the four points between the camera image and the projected pattern, we can compute the homography H_{pc}.

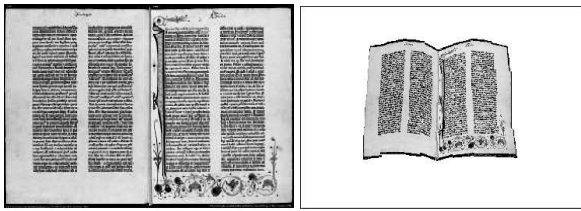H_{so} is determined by the correspondence of each divided rectangular region with the source image, which
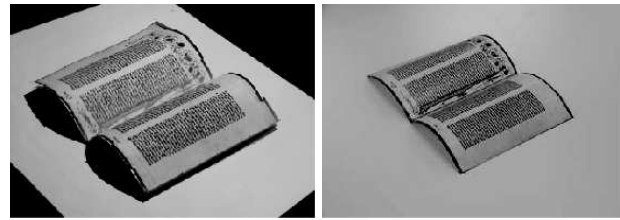
Fig. 5 Source image and generated image.

(a) actual projection image   (b) ideal projection image

$$H_{PO}' = H_{PO} \times H_{re}$$

H_{PO}

an object book

red marker
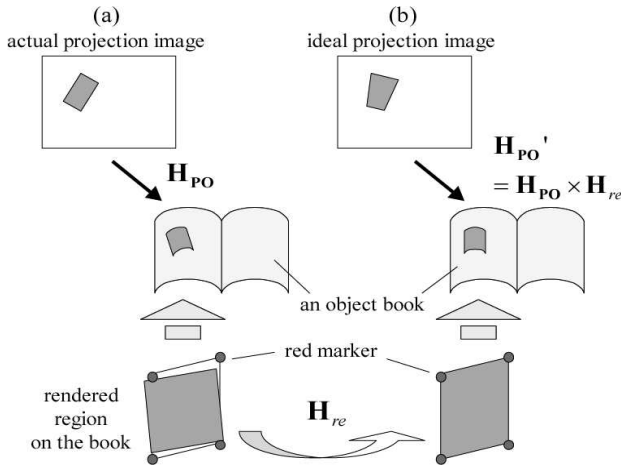
rendered region on the book

H_{re}

Fig. 6 Refining homography H_{po} by using the gap of the rendered region on the object surface.

is defined according to the part of source image should be projected onto the surface region. The position of vertices on the object surface can be represented by the arbitrary scale factor that is the same factor as H_{oc} is determined. The factor is cancelled when H_{sp} is computed finally.

3.3. Generate Warped Image

Each sub-region is warped by the estimated H_{sp} for the

Fig. 8 Comparison between result of projection and printed paper.

region, and then the image to be projected is generated by compounding all the warped images (shown in Fig.5). 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. Such interpolation reduces the hole in the warped image.

3.4. Refine Generated Image

As shown in Fig.4 estimated homography H_{sp} is dependent on H_{pc} and H_{oc}, and the accuracy of the generated warped image is influenced by the error of marker extraction. Since the error of H_{pc} and H_{oc} are accumulated at H_{po}, the generated image can be refined by updating this homography and recalculating H_{sp}. So we perform this refining, when the object is standing it still after rendering the first generated image.

Fig. 6 shows the relation between the calculated homography H_{po} and the ideal homography H_{po}'. As shown in Fig. 6(b), if the ideal projection image is rendered on the book, rendered region looks without distortion. But, distortion occurs because of the above-mentioned error in fact (shown in Fig. 6(a)). This homography H_{po} can be updated by using homography
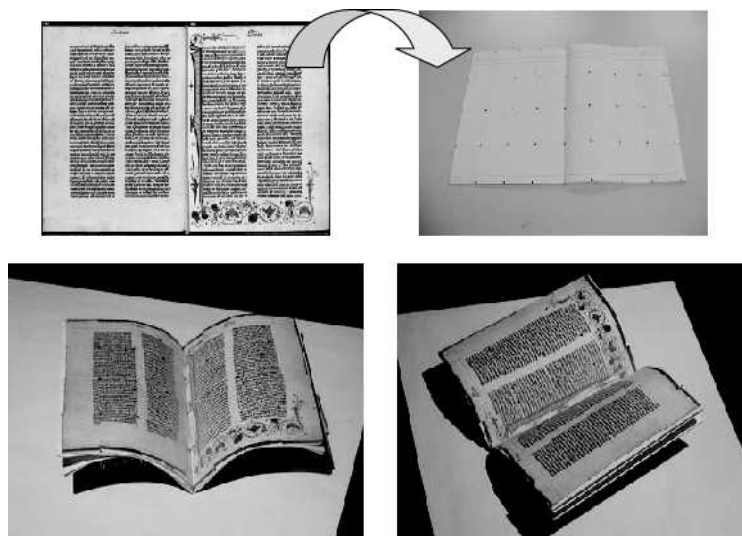

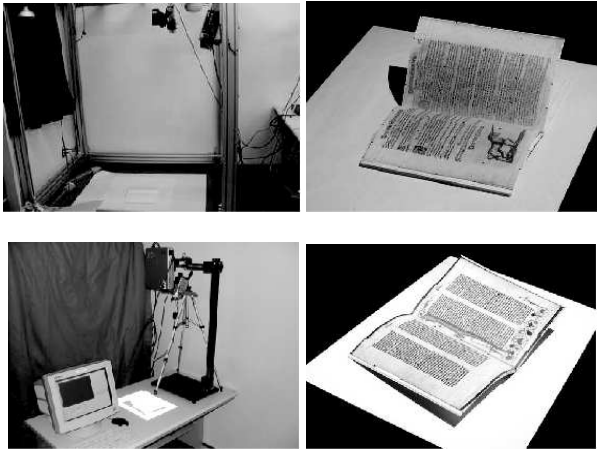Fig. 7 Projection of the document image of the Gutenberg Bible.

Fig. 9 Comparison in the case of different equipments and position.

(a)

(b)

Fig. 10 Comparison of the projection results with different position and shape of a notebook.

H_{re} estimated by using the gap of the rendered region of the first warped image on the object surface.
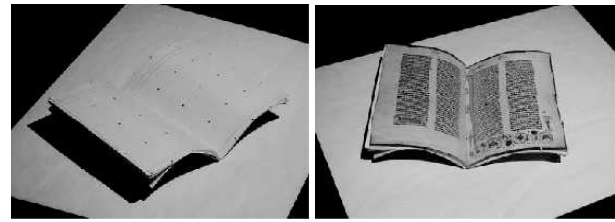
Homography H_{re} obtained by the correspondence of the four vertices of the divided image warped by homography H_{sp} and the four red markers on a book (that is, theoretical value of the four vertices) which are extracted from the captured image is used, updated homography H'_{po} is as follows.
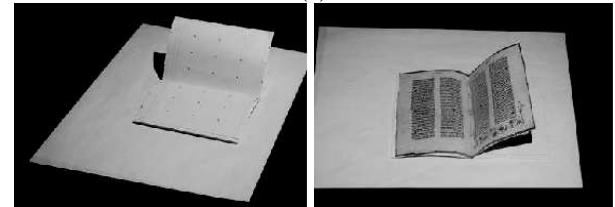
$$H'_{po} = H_{re}H_{po} \qquad (4)$$

In order to obtain the four vertices of each divided image block warped by H_{sp}, the image which added the marker on the four vertices of each block is projected onto the object book, and then the added markers are extracted from the captured frame at that time. Such projection of the image with the markers and extraction of the markers are finished in just a few frames, and performed every several frames (three frames in our implementation shown in the next section), so that users will not notice the projection of the markers.

4. Implementation

We performed the following experiments in order to show the validity of this system. Our system is based on a PC (OS:Windows2000, CPU:Intel Pentium IV 2.8GHz), a camera (SONY TRV-950) and a video projector (PLUS U2-1200). An example source image to be projected onto an object surface is 1024×768-pixel image. We use a B4-sized notebook as an example of book surface on which the digital image is projected. On the surface of the notebook, grids of lattice red markers are printed, so that the surface is divided into sub regions of 4 × 8 rectangles. Fig. 7 shows the appearance of the notebook on which the warped image is projected via the projector. The source image can be projected as if it is printed on the notebook. Fig. 8 shows

the comparison with the real paper on which the same image is printed. Our system avoids the calibration of a camera and a video projector so doesn't depend on their kind or the position of them. Fig. 9 shows the result of the projection in the case that the different camera and projector used with unknown position. We can see the image is correctly displayed by both cases.

Since this system works online, by repeating the series of the processing, the rendered warped image can be automatically updated along with the change of the notebook shape (shown in Fig. 10). Additionally, using this system, a projected source image can also be substituted by any arbitrary image as shown in Fig. 11, because the information on the source image itself is not used in this system. Here we use images of the Gutenberg Bible, which is known as the first printed media in the world. These images are digitized in the HUMI project in Keio University [12]. The original Gutenberg Bible is very precious, so even looking it in the real environment is usually prohibited for avoiding its damage. We apply the proposed system to viewing the digital contents in more realistic situation than viewing on 2D LCD or CRT displays. Thus various applications are expected, such as building a virtual museum by reproducing a precious book like them, or performing newer approach by rendering other an image.

Next, we show the effect of the refining generated projection image, which is described in **3.4**. We tried this refining by different object position ten times. For each trial, we estimated the error of the extracted four vertices of the rendered region and the extracted red marker (that is, theoretical value of the four vertices) before and after refining respectively. As a result, the error was smaller after refining for each times. Table 1 shows the mean and the variance of the errors of all trial. By repeating refining with a threshold, a more accurate image will be obtained.
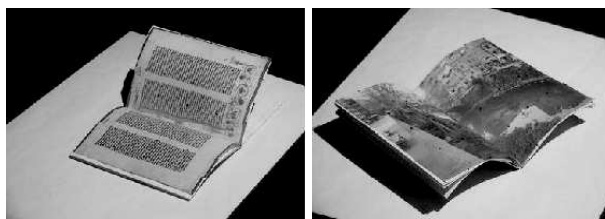
Fig. 11 Comparison of the projection result with different source images.

Table 1. Rendered region error before and after refining.

	Mean (pix)	Variance
Before refining	4.257	6.085
After refining	2.978	3.549

(a) no division	(b) 1×2
(c) 3×4	(d) 4×8

Fig. 12 Comparison of the projection result by the number of division.

Next, the following experiments are conducted in order to show the justification of the proposed technique. In the experiment so far, the notebook is divided into 4×8 and it processed by approximating with a set of 32 rectangle regions. We show the results under different dividing schemes:(a)no division (that is, it being considered that the surface of a notebook is one plane), (b) 1×2, (c)2×4, and (d) 4×8 in Fig. 12. By increasing the number of the division, the projected image gradually gets closer to the notebook surface. If a book surface has more complicated shape, we will easily handle it by increasing the number of division.

Our system takes a few seconds to update because of project the color code pattern and so on. We will improve the system performance so that the projected source can keep being attached onto the surface even while the object shape is changing.

5. Conclusion

In this paper, we described the method for rendering a source image onto an arbitrary shaped surface by a projector. We divide the surface into a number of rectangular regions for approximating each sub-region to a plane, so that homography can be applied to the image transformation. We compute homography of each sub-region among the source image, the object surface, and projector image. Using them, the source image is warped so that the projecting the warped image can be appeared as if the image is printed onto the object surface. By using homography-based method, we can avoid the calibration of a camera and a video projector, so need not the prior setup or the expensive equipment like the conventional method. We also built a system that a source image can be projected onto a notebook surface with arbitrary shape. In this system, the rendered image can be updated if the object surface moves, or refined when it is standing still. Using that, we demonstrate that digital documents can be displayed on the surface of the notebook. This system enables it to project them as if it is printed on a real paper surface of a book.
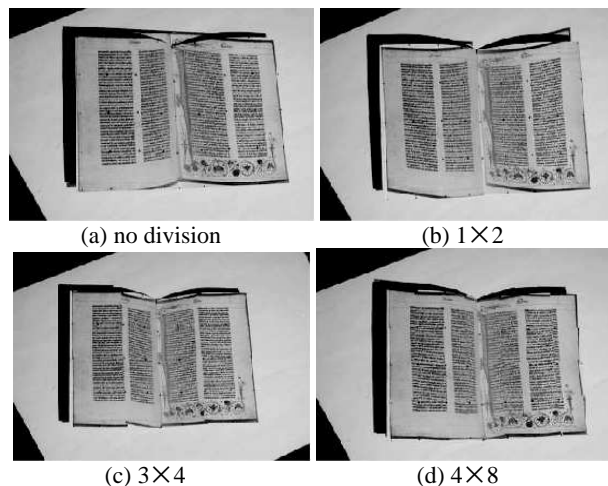
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