OPTICALLY WRITTEN WATERMARKING TECHNOLOGY USING ONE DIMENSIONAL HIGH FREQUENCY PATTERN

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Abstract: We propose a new optically written watermarking technology that uses a one dimensional high frequency pattern to protect the portrait rights of 3-D shaped real objects by preventing the use of images captured illegally with cameras. We conducted experiments using a manikin's face as a real 3-D object assuming that this technology would be applied to human faces in the future. We utilized the phase difference between two color component patterns, i.e., binary information was expressed if the phase of the high frequency pattern was the same or its opposite. The experimental results demonstrated this technique was robust against the pattern being deformed due to the curved surface of the 3-D shaped object and a high accuracy of 100% in reading out the embedded data was possible by optimizing the conditions under which data were embedded. As a result, we could confirm the technique we propose is feasible.

1 INTRODUCTION

The importance of techniques of digital watermarking has recently been raised because increasingly more digital-image content is being distributed throughout the Internet. Various approaches to concealing watermarking in images have been developed ((I. J. Cox et al., 1997), (M. D. Swanson et al., 1998), (M. Hartung et al., 1999)). However, conventional digital watermarking techniques rest on the premise that people who want to protect the copyright of their content have the original digital data and can embed watermarking by digital processing. However, there are some cases where this premise does not apply. One such case can arise for images that have been produced illegally by people taking photographs of real objects that have high value as portraits, e.g., art works at museums that have been painted by famous artists or faces of celebrities on a stage. The images produced by capturing these real objects with digital cameras or other image-input devices by malicious people have been vulnerable to illegal use since they have not contained digital watermarking.

We have proposed a technology that can prevent the images of objects from being used in such cases ((K. Uehira et al., 2008), (Y. Ishikawa et al., 2010)). It uses illumination that contains invisible information on watermarking. As the illumination contains the watermarking, the image of a photograph of an object that is illuminated by such illumination also contains watermarking. We treated flat objects in a previous study assuming famous paintings were being illegally copied and used a 2-dimensional high frequency patterns as watermarking patterns. We demonstrated that this technique effectively embedded the watermarking in the captured image.

However, if we use this technique for 3-D shaped objects that have curved surfaces, the embedded information for watermarking cannot be read out correctly because the projected patterns on the surface of objects are deformed. We previously tried to correct deformation in the projected watermarking pattern using two dimensional grid patterns (Y. Ishikawa et al., 2011). We found this technique made it possible to correct deformation and accurately read out watermarking information. However, it needs the additional projection for grid pattern in addition to watermarking pattern, therefore, it cannot be applied to moving object.

This paper proposes a new technique that does not need patterns to be corrected. It uses one dimensional high frequency patterns as watermarking patterns. A one dimensional pattern is expected to be robust to deformation of the projected pattern because of its simplicity compared to two-dimensional patterns. We used a human face as a

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real object in this study assuming its portrait rights were protected. This paper also presents results obtained from experiments where we evaluated the accuracy with which the watermarking could be read out with our new technique.

2 OPTICAL WATERMARKING AND PROPOSAL FOR 1-D OPTICAL WATERMARKING

Figure 1 outlines the basic concept underlying our technology of watermarking that uses light to embed information. An object is illuminated by light that contains invisible information on watermarking. As the illumination itself contains the watermarking information, the image of a photograph of an object that is illuminated by such illumination also contains watermarking. By digitizing this photographic image of the real object, the watermarking information in binary data can be extracted in the same way as with the conventional watermarking technique. To be more precise, information to be embedded is first transformed into binary data, “1” or “0”, and it is then transformed into a pattern that differs depending on whether it is “1” or “0”. This pattern is transformed into an optical pattern and projected onto a real object. It is this difference in the pattern that is read out from the captured image.

The light source used in this technology projects the watermarking pattern similar to a projector. Since the projected pattern has to be imperceptible to the human-visual system, the brightness distribution given by this light source then looks uniform to the observer over the object, which is the same as that with conventional illumination. The brightness of the object’s surface is proportional to the product of the reflectance of the surface of the object and illumination by incident light. Therefore, when a photograph of this object is taken, the image on the photograph contains watermarking information, even though this cannot be seen.

The main feature of the technology we propose is that the watermarking can be added by light. Therefore, this technology can be applied to objects that cannot be electronically embedded with watermarking, such as pictures painted by artists.

We used a method in our previous study that used two-dimensional inverse Discrete Cosine Transform (iDCT) to produce the watermarking pattern. The illumination area was divided into numerous numbers of blocks. Each block had 8 x 8 pixels. We expressed 1- bit binary data as “1” or “0”

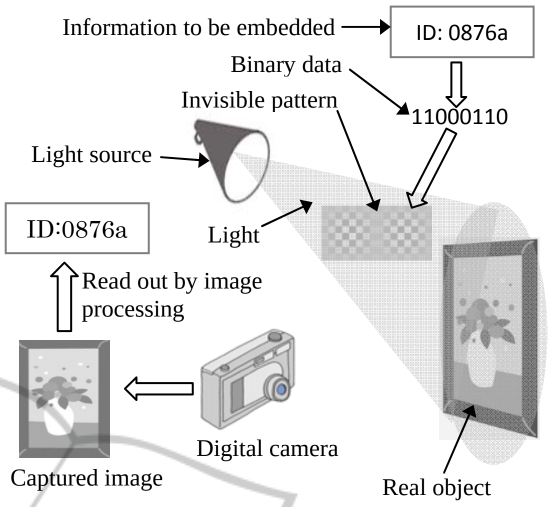

Figure 1: Basic concept underlying technology of watermarking that uses light to embed data.

by using the sign of the high-frequency component. This method, however, is not robust to deformation of the projected pattern when it projected onto a curved surface.

In contrast, we propose the one dimensional high-frequency pattern in this study shown Fig. 2, where each vertical pixel line has 1-bit binary information of “1” or “0”. We use two color components to express “0” or “1”, i.e., if the phase of the high-frequency pattern of two color components are the same, the binary information is “1” and if not, it is “0”. Even if we cut out a small area of the pattern shown in Fig. 2 using this pattern, we can determine whether the binary information is “1” or “0” because we just need to check if the phase of the patterns of two color components are the same or not in the line.

We assumed that for a small area, displacement of the projected pattern caused by the curvature of the object surface would not be very large. Since we captured the object image with double resolution (as will be explained later), the phase calculated from some pixel lines was not affected by the deformation seen at the right of Fig. 2, so that the phase of the pattern changed substantially. This technique is expected to be robust to deformation of the projected pattern, since we can use an arbitrarily small area in regard to the y-(or x-) direction while for a two dimensional pattern, the area where one bit binary data are embedded is fixed and the effect of deformation is significant.

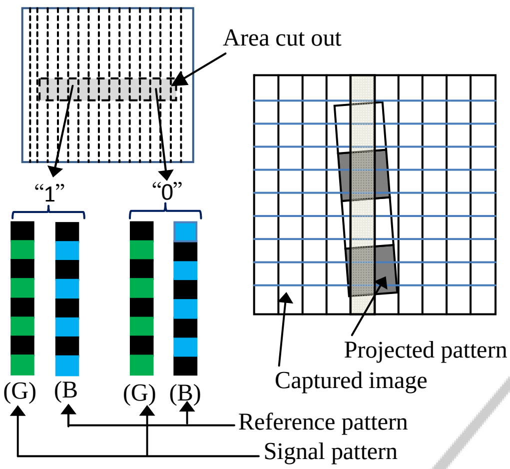

Figure 2: One dimensional optical watermarking pattern.

3 EXPERIMENTS

We carried out experiments to demonstrate the feasibility of the technology we propose in this study. We made test patterns where each vertical pixel line was assigned the one bit information in Fig. 2. We used a color image, and the G-color component was used for the signal pattern and the B-color component was used for the reference pattern. We set the average brightness (DC) to 200 and the highest-frequency component (HC) was changed as an experimental parameter. These values were on an 8-bit gray scale whose maximum was 255.

We used a digital light processing (DLP) projector that had 1024 x 768 pixels for each color to project the watermarking image. We used the face of a manikin as a real 3-D object. Figure 3 is a photograph where a watermarking image has been projected onto the manikin's face. The whole projected area was 80 x 60 cm; therefore, the manikin's face was part of the whole projected area. We confirmed that high frequency patterns projected onto the manikin's face were imperceptible when they were viewed at a distance of 2 m.

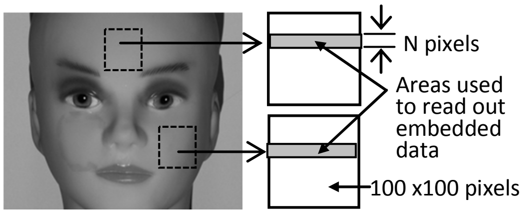

Figure 3: Manikin's face used as 3-D real object in experiment. Parts of areas in each rectangular area were cut out to read out embedded binary data.

The projected patterns were captured with a digital camera that had 3906 x 2602 pixels. The captured image had over twice the pixel density of the projected image. This was because over twice as many pixels were needed according to the sampling theorem to restore the original high frequency patterns in the projected image. After it was captured, we changed this ratio to just twice by digital processing. The high frequency component in the x-row of the captured image was calculated with Eqs. 1 and 2

$$HC1[x] = \sum_{i}^{N} H1[i][I[i][x] \quad \text{--- and (1)}$$

$$HC2[x] = \sum_{i}^{N} H2[i][I[i][x] \quad \text{--- (2)}$$

where I[i][x] indicates image data at pixel [i][x] and H1[i] and H2[i] are the following matrices.

H1[i]=1 (if the remainder of i by four is 0 or 1),
-1 (if the remainder of i by four is 2 or 3)

H2[i] =1 (if the remainder of i by four is 1 or 2)
-1 (if the remainder of I by four is 0 or 3)

The summations in Eqs. 1 and 2 were done over N pixels in the y-direction. We chose 8, 12, 16, 32, and 60 as N. Since the captured image had twice as many pixels as the projected image, we obtained a frequency component that was half the highest frequency. We calculated two frequency components, HC1[x] and HC2[x], which had the same frequency but their phases differed by 90 degrees using H1[i] and H2[i] to obtain the phase of the pattern in the captured image with Eq. 3.

$$\theta[x] = \arctan(HC2[x]/HC1[x]) \quad \text{--- (3)}$$

We obtained θ[x] for the signal pattern and the reference pattern. We determined the binary data at x to be "1" if the absolute value of the difference between the phases of the two patterns was less than 90 degrees and we determined it to be "0" if it was over 90 degrees. This was because we set the phase of the original signal and reference pattern to be the same when we assigned the "1" of binary data and we set the difference between two patterns to be 180 degrees when we assigned the "0" of binary data, as can be seen in Fig. 2.

We cut out the two areas of the image on the manikin's face shown in Fig. 3. One was an image on the forehead that was relatively flat and the other was an image on the cheek that was largely curved.

Table 1: Accuracy with which embedded data were read out. N indicates number of pixels.

(a) Forehead. (%).

HC \ N	8	12	16	32	60
20	90.0	97.5	95.0	82.5	85.0
30	95.0	95.0	95.0	85.0	87.5
40	100.0	100.0	100.0	97.5	90.0
50	97.5	97.5	100.0	87.5	60.0

(b) Cheek (%).

HC \ N	8	12	16	32	60
20	95.0	95.0	100.0	97.5	92.5
30	100.0	100.0	100.0	90.0	55.0
40	97.5	100.0	100.0	82.5	42.5

4 RESULTS AND DISCUSSION

Table 1 lists the experiment results for the accuracy with which the embedded data were read out. The accuracy is indicated by the percentage of data that were read out correctly from the entire amount of data. We established four main findings from Table 1: 1) Accuracy was very high for small numbers of N under 16 not only for the forehead area but also for the cheek area where the surface was largely curved, 2) it was highest at N=16, 3) it was poor for a large number of N over 32 for both areas, and 4) accuracy was poor for an HC of 20.

The reason that accuracy was excellent for small numbers of N and poor for large numbers was because the results from calculations were largely affected by the object surface being deformed when the area used for the calculations was elongated. As N decreased, on the other hand, the summation of the frequency components in Eqs. 1 and 2 decreased, and this caused a decrease in accuracy. This was considered to be the reason for accuracy to peak at N=16. However, the results revealed that accuracy for very small N under 12 was still very high. This reason for this was because we chose a human face as the 3-D shaped object, which had uniform characteristics with regard to its image signal. As it did not have a high-frequency component, the values were almost all obtained from the projected pattern.

Result 4) was what we had expected because of the small frequency component.

As we can see from Table 1, a high degree of accuracy of 100% in reading out the embedded data is possible by optimizing the conditions for reading data. Therefore, we could confirm the feasibility of the proposed technique. Moreover, since we can use an error correction technique in practice, over 90% accuracy is sufficient for practical use.

5 CONCLUSIONS

We proposed one dimensional optical watermarking to protect the portrait rights of 3-D shaped real objects and we conducted an experiment using a manikin’s face as a real 3-D object assuming this technology would be applied to human faces in the future. We used a method of phase difference where two out of R, G, and B-color components were used and binary information was expressed if the phase of the high frequency pattern was the same or its opposite. The experimental results demonstrated this technique was robust to deformation of the pattern due to the curved surface of the 3-D shaped object and a high degree of accuracy of 100% in reading out the embedded data was possible by optimizing the conditions for reading data. As a result, we could confirm the feasibility of the proposed technique.

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