Synchronization-free single-shot detection of imperceptible AR markers in a high-speed video display

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Abstract In this paper, we propose a method of embedding augmented reality (AR) markers in a displayed video so that they are imperceptible to human eyes. Using a high-speed projector, we display a set of markers that change their positions rapidly so that human eyes cannot perceive them, while a camera with a sufficiently short exposure time is able to detect at least one marker in the image even if there is no means of synchronization between the projector and the camera. Details of the marker design are presented.

Keywords: High-speed Projector, Marker detection, Information Hiding

1. Introduction

Digital signages are widely utilized to display digital contents such as images and video for many purposes including advertisement. If we add machine-readable codes such as AR (Augmented Reality) markers on displayed contents, it becomes possible for passing-by viewers to obtain additional information by pointing their camera-equipped mobile devices to a display. However, inclusion of such artificial codes may limit contents design and may spoil the view.

Technologies for information hiding into displayed images can help tackle this problem. As a promising class of such technologies, it has been proposed to utilize high-speed video displays, which can display information that human eyes cannot perceive but specially designed imaging systems can. Matsushita et al. [1] proposed to hide information in fast blinking light source and to receive it with a high-speed camera, but the need for high-speed cameras makes viewer-side devices expensive. Cotting et al. [2] and McDowall et al. [3] proposed to display hidden information for a very short time in video sequences so that cameras synchronized to that timing can only receive it. The need for the synchronization in advance makes these methods difficult to be used by passing-by viewers. Grundföfer et al. [4] proposed to embed information in inter-frame differences. This also requires synchronization and is weak for fast camera motion. Niidome et al. [5] removed the need for synchronization in advance, by dynamically controlling the frame rate of a viewing camera so that it automatically synchronizes to hidden frames. However, such a controlling mechanism is not always available in viewer-side devices, and the auto synchronization process takes an unignorable time.

This paper proposes a novel method of displaying imperceptible AR markers by which the need for synchronization is completely removed.

2. Proposed method

We use a DLP (Digital Light Processing) projector as a high-speed video display. In DLP technology, a video frame is composed of many binary image frames produced by DMD (Digital Micromirror Devices) switching at a high speed.

Consider displaying an AR marker in a binary frame. Because a binary frame is too short, it is difficult for human eyes to see. In order to enhance the hiding effect, we use pairs of markers with complementary patterns displayed at the same positions in nearby binary frames.

We embed at least one marker in each binary frame while the positions of the markers are changed with time. Let τ and T denote the displayed period of each binary frame and the displayed period of a video frame, respectively. A marker is displayed at most n times in the same position within a video frame. If $n\tau/T$ is small enough, markers are not perceived by human eyes.

On the other hand, because any of binary frames include at least one marker, marker detection by a camera is possible at any time as long as the exposure time of the camera is short enough to fall within a single binary frame. Consequently, we do not need a fast camera or a camera synchronized to the video display. By assigning different IDs to the markers displayed at different positions, one can reconstruct the position and orientation of the camera relative to the video display coordinate frame regardless of which marker is detected.

An issue here is that marker detection becomes difficult

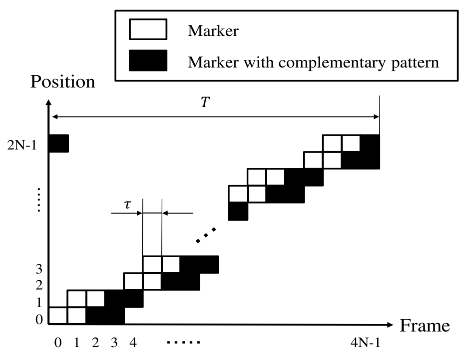
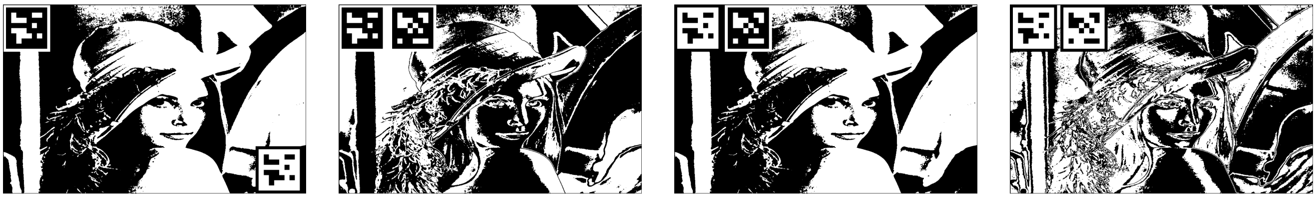


Fig.1 Time-space diagrams of a embedding method using a complementary set of markers. At least, one marker is always perfectly imaged with the method



$i = 0$ $i = 1$ $i = 2$ $i = 3$

Fig.2 Examples of projected images. Each marker is embedded into two consecutive frames. M_0 is embedded in $i = 0$ and $i = 1$, M_1 is embedded in $i = 1$ and $i = 2$, M'_0 is embedded in $i = 2$ and $i = 3$, M'_1 is embedded in $i = 3$ (and $i = 4$), and M'_{2N-1} is embedded in $i = 0$ (and $i = 4N - 1$).

when a camera exposure period overlaps two consecutive binary frames. In this case, a marker in one of the binary frames may be disturbed by another marker or other contents in the other binary frame. In order to solve this problem, we embed a single marker in two consecutive binary frames and arrange the combination of markers so that any exposure period shorter than τ falls within the displaying duration of at least one marker. Conditions for a marker M_i and its complementary version M'_i are displayed in the i-th binary frame are given by

$$\begin{array}{lll} M_{2j} & : & i \equiv 4j, 4j+1 \pmod{4N} \\ M_{2j+1} & : & i \equiv 4j+1, 4j+2 \pmod{4N} \\ M'_{2j} & : & i \equiv 4j+2, 4j+3 \pmod{4N} \\ M'_{2j+1} & : & i \equiv 4j+3, 4j+4 \pmod{4N} \end{array}$$

where j is an integer and $2N$ is the number of embedding positions of markers. A video frame contains $4N$ binary frames. These conditions are illustrated in Fig.1. Examples of projected images are shown in Fig.2.

3. Experiments and results

A grayscale image in which the markers are embedded was projected onto a screen with Texas Instruments DLP LightCrafter 4500. ARToolKitPlus [6] was used as AR markers. Images of the screen were taken with Point Grey Research Flea3 FL3-U3-13Y3M-C (480×320 pixels, 30 fps) and marker detection was tried in each image. We took 1000 images for one experiment and 10 experiments were performed. The ratio of the number of frames where markers were successfully detected was evaluated. We set τ, the exposure time of the camera and $2N$ to 500 μs, 100 μs and 24, respectively.

The results by the proposed method is shown in Fig.3 (d). For comparison, the results without the proposed marker arrangement are also shown as (a)–(c), among which (a) and (b) are without complementary patterns. The best performance was obtained by the proposed method.

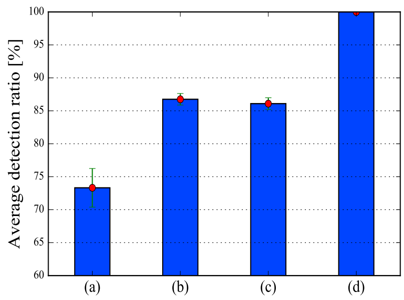


Fig.3 Average marker detection ratios. Error bars indicate $\pm 3\sigma$ uncertainty. (d) is with the proposed marker arrangement, while (a)–(c) are not. (c) and (d) are with complementary patterns, while (a) and (b) are not. $2N = 48$ for (a), while $2N = 24$ for (b)–(d). (b) made the markers slightly perceptible by human while the others did not.

4. Conclusion

We have proposed a method of detecting imperceptible markers embedded in a high-speed video display. Because any of binary frames have at least one marker, we can detect markers from a single image without a fast camera or a synchronized camera. In future work we will investigate suitability of different types of markers for our method.

Acknowledgement Part of this work was supported by JSPS Grant-in-Aid 16H02853, 16H06536 and JST ACCEL.

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