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Imperceptible Projected Marker Codes with Application to Calibration-Free Projection Mapping

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Abstract: *This paper reviews our recent efforts on Digital Micromirror Device (DMD)-based approaches to embed imperceptible marker codes into video projection. An application to calibration-free projection mapping onto a moving surface is also described.*

1. Introduction

Machine-readable marker codes such as 2D barcodes play various roles in many fields. Showing them on graphical displays is also a popular practice to provide additional information as well as the geometrical relationship between the display surface and a viewing device such as a camera. It is sometimes useful to make those codes imperceptible to human eyes such that they do not disturb the main displayed content. There are a wide range of techniques to achieve this, including the use of imperceptible optical properties [1-3], high temporal frequency components of signals [4-11], high spatial frequency components of patterns [12], insensibly small differences of luminance [13], and combinatory use of them.

A Digital Micromirror Device (DMD) is a spatial light modulator used in Digital Light Processing (DLP) projectors. Because a DMD is able to display fast flapping binary patterns at a rate of tens of kHz, it is suitable for taking the high temporal frequency approach while relying on a mature and widely used type of display technology. This paper reviews the efforts in the author's group for expanding the possibilities and applications of imperceptible codes displayed with DMD projectors.

2. Auto-synchronizing marker code

A typical usage of a DMD display in embedding imperceptible information is to insert a short period of an embedded code frame periodically such that the period is short enough not to be visible to human eyes, and let the exposure time of a viewing device synchronized to those code frames [5, 6]. If the synchronization can be acquired automatically, applications with multiple displays and multiple viewing devices, possibly owned by general public users, would be realized.

We proposed a technique that dynamically controls the frame rate of a camera such that the camera exposure period is automatically synchronized to displayed code frames [14]. It is an instance of a phase-locked loop (PLL) technique in which the pixel intensities of the marker code are received as input and the exposure control signal of the camera is generated as output [15]. A key idea is that the insertion period of the marker code frames into the displayed video is not perfectly constant. Instead, even-numbered code frames are inserted a little earlier, and odd-numbered frames a little behind. By analyzing the intensities of captured codes, it is possible to distinguish whether the camera capturing phase is in advance or behind compared to the code display phase.

3. Synchronization-free marker code

Another approach toward the same goal is to remove the necessity of synchronization. We developed a marker code embedding scheme in which small marker codes are sparsely distributed in space domain as well as in time domain within a displayed video [16].

Whenever a camera captures an image of the display surface with a sufficiently short exposure time, it is guaranteed that a small number of markers are detected. Each marker code provides information on where it should be in the display surface coordinates such that the camera is able to recover its geometrical pose with respect to the display surface coordinates. In the meanwhile, when we look at an arbitrary pixel in the display, it convey the pixel intensity of the main content for the most of the time and the insertion of marker codes occupies only a small fraction of the time.

4. Application to calibration-free projection mapping

Projection mapping of video content onto a real object surface necessitates accurate registration between a projected image and the surface. When cameras are introduced to measure the surface geometry, accurate calibration between the projector and the cameras is required, which is in general a time-consuming task.

We proposed a calibration-free approach, in which the projected content as well as the surface is visually tracked with a camera, and a feedback control is applied such that the misalignment between them is minimized in real time. Implementation of this approach is relatively simple when tracking of the surface and the content is decoupled [17]. However, when a projected content is superimposed on the surface texture, decoupling the surface and the content in a camera image is challenging. When a movie content is projected, tracking the movie is also a challenge.

We applied the embedded-code approach to this problem [18], in which the proposed tracking algorithm is able to separate the projected code pattern and the surface texture from a single image without the need of time averaging or frame differencing of captured images, which will fail when the target surface moves rapidly.

The algorithm is implemented with a DMD projector equipped with our custom controller [19-21], in which 400-fps code patterns inserted within a 2,400-fps binary pattern sequence are tracked to achieve low-latency mapping.

7. Conclusion

This paper reported our recent efforts on improvement of DMD-based embedded-code techniques and application to dynamic projection mapping.

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