Minimizing Latency for Augmented Reality Displays: Frames Considered Harmful

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Abstract: In Optical See-Through Augmented Reality (OST-AR) systems, latency accumulates throughout all stages, from tracking, to application, to image generation, scanout, and display. In this work, we present initial results from a new image generation approach for low-latency displays such as those needed in head-worn AR devices (e.g. Google Glass, Epson Moverio BT-200).

Grayscale image display at max **binary** rate 10,000 – 20,000 Hz!
Readily extendable to color.

Proposed low-latency binary image generation method (*Figure 1*):

Question 1: Assuming that the **Desired Image** (*grayscale*) and the **User Perceived Image** (*grayscale*) are known, how to compute the **Binary Projector Image**?

Answer 1: Compare them pixel by pixel → **turn on** the binary pixel if needs **more light**
→ **turn off** the binary pixel **otherwise**

Question 2: How to compute the **User Perceived Image**?

Answer 2: Integrate over a window of 64 (~3 ms) most recently projected binary images.

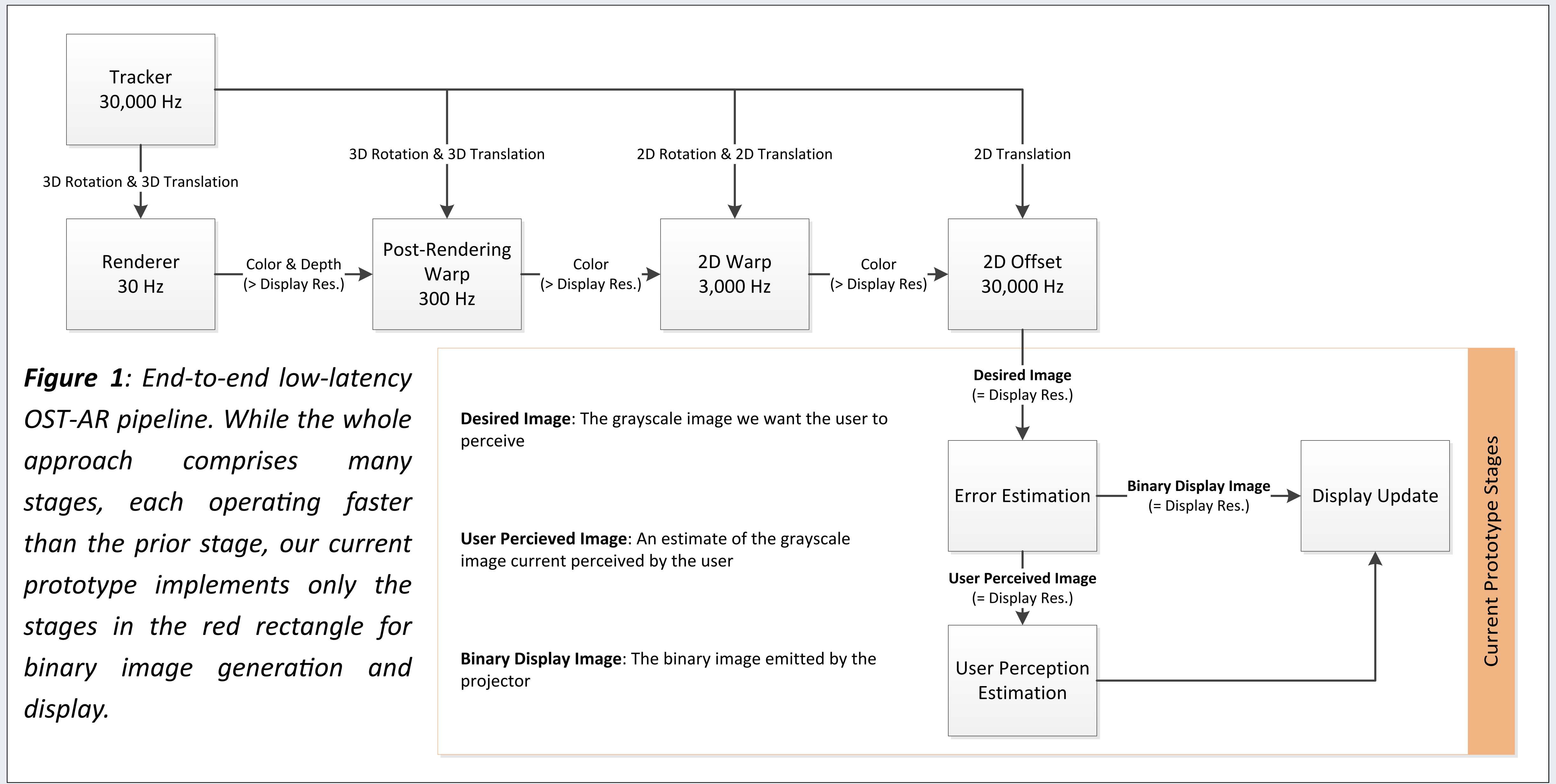


***Figure 1**: End-to-end low-latency OST-AR pipeline. While the whole approach comprises many stages, each operating faster than the prior stage, our current prototype implements only the stages in the red rectangle for binary image generation and display.*

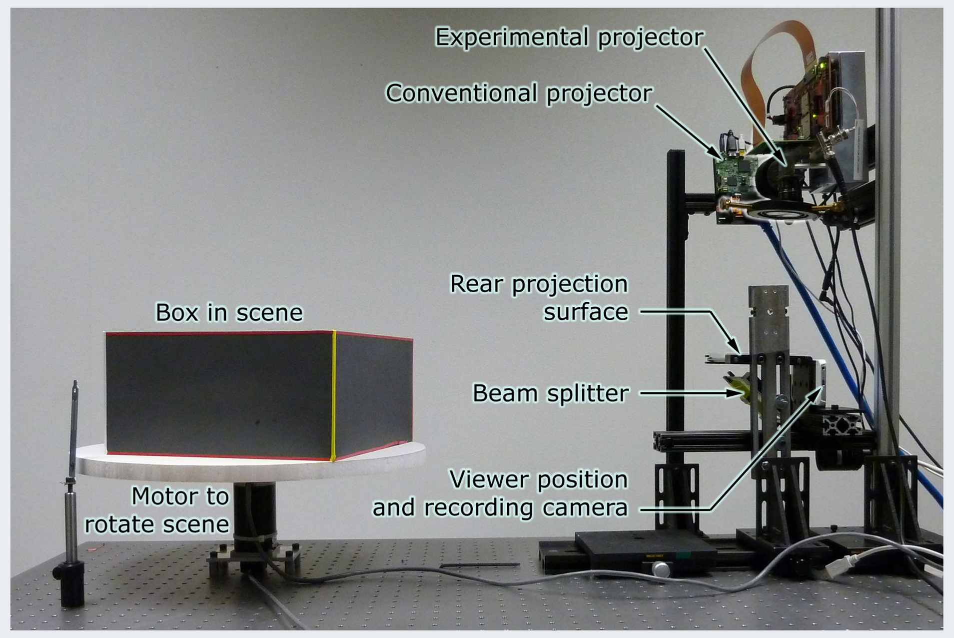


***Figure 2**: Experimental setup. The conventional projector is DLP Lightcrafter (@ 60 Hz color). The experimental projector is TI Discovery 4100 Development Kit (@ 22,727 Hz binary; @ 291 Hz grayscale (using conventional pulse width modulation (PWM) to achieve various levels of light intensity); @ 97 Hz color (hardware upgrade required, i.e., not natively supported)). The recording camera is 120 Hz.*

***QR Code for Results Video**:*

Algorithm Demonstration

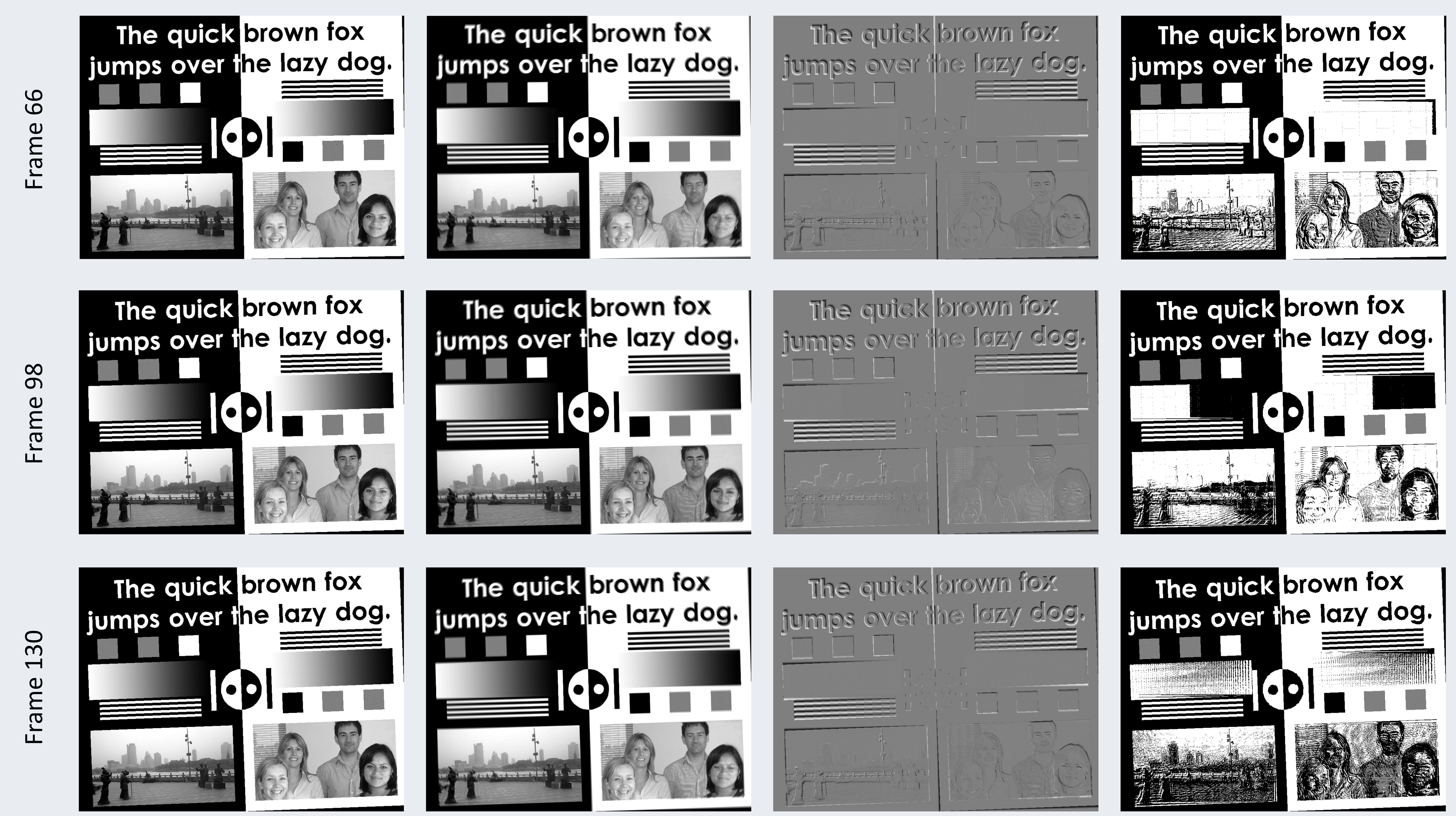
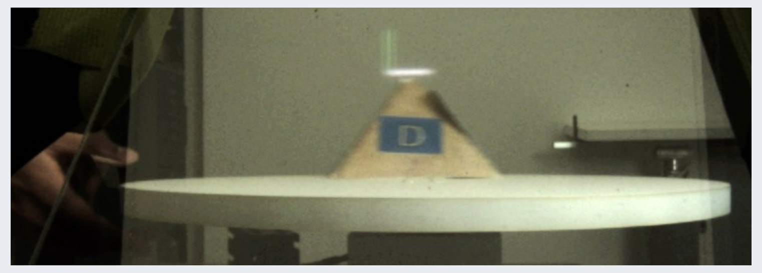


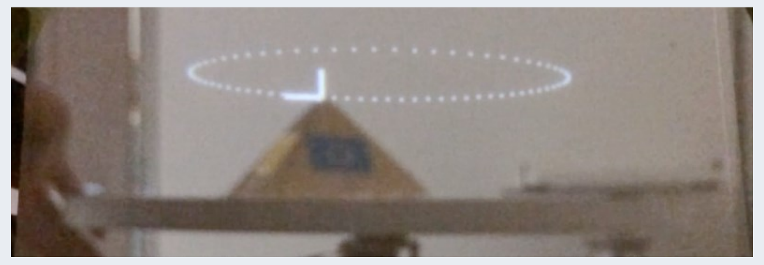
***Figure 3**: Sample images used by our algorithm. The resulting displayed binary image is "neither here nor there," but always approaches the constantly changing desired image.*

Preliminary Results

Experiment 1: Latency



(a) Conventional 60 Hz color display



(b) Experimental display at 1 kHz

***Figure 4**: AR registration of a spinning pyramid using the same tracking and rendering but different displays.*

Experiment 2: Rotating Grayscale Pattern projection

(a) 60 Hz grayscale projector *(b) 22,727 Hz binary projector (using our binary image generation algorithm)* *(c) 60 Hz color projector*

***Figure 5**: Grayscale image projection. (a) The image is generally sharp within each consecutive frame, though these two frames are distinctly visible, which results in jumpy motion. (b) The center of the image is sharper while the outside edges are more blurred, which results in smooth motion. (c) Similar to (a), the image is generally sharp for a single color channel, though the color channels are spatially separated.*

Conclusion: Our approach produces visually pleasing results. Rapid updates decrease or eliminate the "swimming" artifacts induced by latency, and the imagery shown by our proposed display is more natural and resembles motion blur, which is more acceptable to viewers.

Future Work: (1) Efficient FPGA implementation of the proposed algorithm; (2) High-speed image scanout from GPU; (3) Extension to color images; (3) Explore the effects of eye movements.

***Reference**: Feng Zheng, Turner Whitted, Anselmo Lastra, Peter Lincoln, Andrei State, Andrew Maimone, and Henry Fuchs. "Minimizing Latency for Augmented Reality Displays: Frames Considered Harmful." International Symposium on Mixed and Augmented Reality (ISMAR 2014), Sept. 2014, Munich, Germany.*