Electronic Appendix

Sun Position Estimation and Tracking for Virtual Object Placement in Time-lapse Videos

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In this electronic appendix, we provide further details about experimental evaluation of our approach and qualitative (visual) and quantitative results for three additional time-lapse videos.

We evaluate our approach on time-lapse videos found on the Internet and we do not have the exact ground truth Sun position for these videos. We approximate the ground truth position for our purposes. To this end, we establish a real environment similar to the one in the video and obtain similar object-shadow relationships with the ones in various frames by using an artificial light source. This experimental approach generates a good approximation about the ground truth Sun positions in the videos. We also support these findings by making angular measurements on the object-shadow pairs of randomly selected frames of the videos.

The shadow tracking algorithm works better when the tracked shadow is on a smooth surface. The surfaces with irregular textures such as grass or bumps may distort the smoothness of the shadow; hence, the algorithm may fail to track the shadow on these surfaces. Additionally, sometimes the tracking algorithm may confuse the texture edges with the shadow edges when they become too close to each other, but this does not cause a problem because the tracking algorithms can detect the shadow after a few frames and the smoothing filters can handle such errors.

The image-based approach by Chen et al. [1] estimates the illumination from a single image for lighting virtual objects in the image, which is what we do for the frames of time-lapse videos. We use their approach, with some modifications, for the Sun position estimation in the first frame of the video. Then, we update the Sun position according the changes in the size and position of the hard shadow that we select for tracking. As an alternative to our approach, we could apply Chen et al.'s method for every video frame. However, this would be much more computationally demanding because we can achieve real time frame rates after the initial preprocessing stage just by updating the Sun position based on the tracked hard shadow.

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Fig. 1 shows graphs that compare the estimated elevation and azimuth angles with the ground truth values for three additional time-lapse videos [2,3,4]. The graphs also show the elevation and azimuth angles before smoothing filters are applied. Fig. 2 present the visual results of the application of the proposed method on these videos. The still frames show that the virtual objects are properly illuminated and seamlessly integrated into the real scenes (please confirm the accompanying video).

Because we use a pixel-wise approach to track the shadow edge, the resulting elevation and azimuth angles do not follow a smooth pattern, which causes jittering during the illumination of virtual objects inserted into the video. To alleviate this problem, we fit first-order polynomials in a least squares sense to the elevation and azimuth angle values. If the algorithm fails to track the shadow in a number of frames, the smoothing procedure can handle this by interpolating the missing values based on the values for other frames. For example, the proposed algorithm fails to track the shadow in many frames between 200th and 300th frames in the rod time-lapse video because of the misleading texture in the surface (see Fig. 1 (b)). Because the shadow is tracked correctly in other parts of the video, the smoothing procedure successfully interpolates the missing values.

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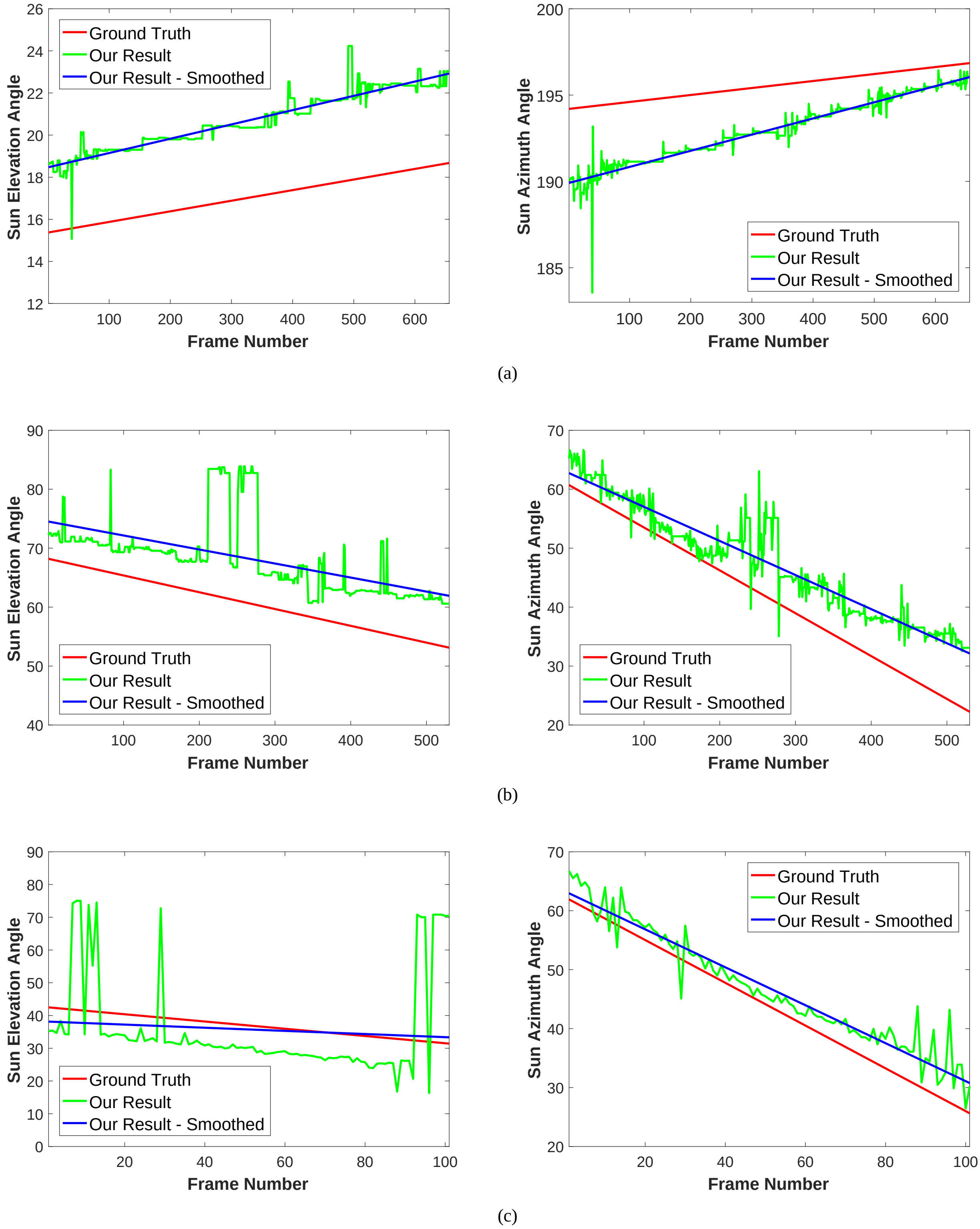
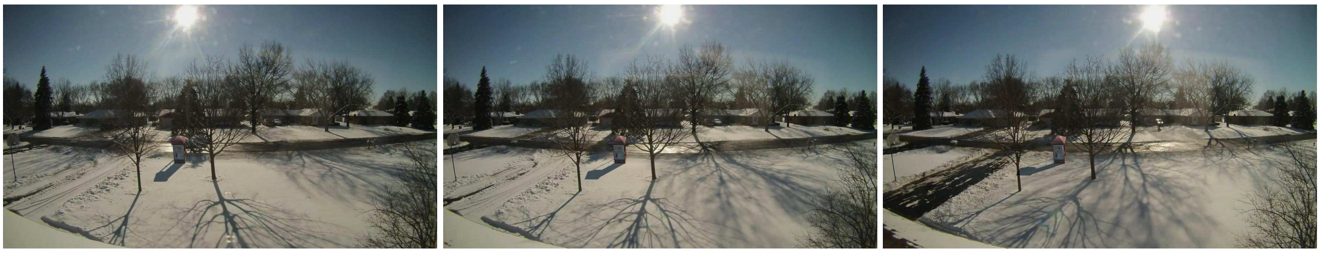


Fig. 1: Comparison of the elevation (left) and azimuth angles (right) of the Sun with ground truth values for the time-lapse videos. (a) Cat Time-lapse, (b) Sundial Time-lapse, and (c) Snowy Time-lapse.

(a)

(b)



(c)

Fig. 2: Still frames from the time-lapse videos. The illumination of the virtual object changes synchronously with the Sun position. (a) A small lion statue behind the cat statue, (b) rocks to the left of the sundial, and (c) public telephone booth between the two trees.

References

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