Hiding Seams in High Dynamic Range Panoramas

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This poster presents a simple and efficient method for stitching sections of a high dynamic range (HDR) panorama, taking advantage of perception to minimize visible seams. Most approaches to panoramic stitching require exact or nearly exact overlay of the input images in order to produce a seamless blend. Most methods also require identical image exposures, and do not work in HDR. We overcome these limitations with an approach that is fast and memory-efficient, working on a scanline at a time within each overlapping rectangle. Input to the algorithm is a set of HDR images with correspondence points between each pair to be joined, one point pair per seam. These correspondence pairs may be selected manually, or generated automatically using a technique such as [Pollefeys & Van Gool 2002].

Our technique is based on two simple observations:

- Low frequencies may be blended smoothly without introducing visible artifacts.
- High frequency splices are interpreted as edges, but can be hidden by edges in the input.

We begin by separating the input into two bands: a high-frequency band corresponding to the underlying image resolution, and a low-frequency band corresponding to $1/16^{th}$ this resolution. The low-frequency bands from the two inputs are blended smoothly in the overlapping region, using a sinusoidal blend function. This avoids the appearance of mach band artifacts when the exposures are slightly different. Starting from HDR input, we can normalize the source images based on their overlap to further minimize exposure differences.

The high-frequency band is spliced together rather than blended, but only at edges detected in the input. In each overlapping scanline, the left portion is used up until a prominent, corresponding edge is found in both scanlines, at which point we switch over to the high frequencies of the right scanline. An edge will appear at the splice, but where there was already an edge in the input. If no edges are detected, we fall back on a simple blend of high frequencies as well. Thus, we preserve high frequencies only at edges, and avoid creating false edges in our result.

Limited horizontal squashing and stretching of the scanlines (up to 15%) is used to maximize the likelihood that input edges will line up. Furthermore, edges near to the previous scanline's splice are preferred to reduce horizontal artifacts caused by switching splice locations at each scanline. This technique works well for vertical features, but occasionally runs into difficulties with moving, amorphous shapes.

Neither blending nor splicing works alone if the inputs are not perfectly aligned. Blending results in ghost artifacts and blurring, and splicing results in false edges at the seam. If the images are not identically exposed, splicing will also yield a pronounced seam line, as shown in Figure 1a. (This figure is reproduced on the back cover of the printed APGV '06 proceedings.)

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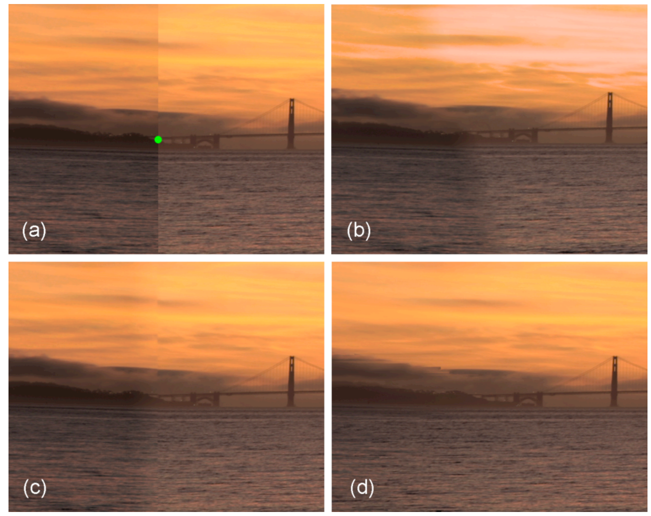

Figure 1. (a) Simple splice with correspondence point, (b) Photoshop™ results, (c) Burt-Adelson method, (d) Our method.

Figure 1b shows that even when the inputs are well-aligned, simple blending gives rise to blurring in the results. Figure 1c improves upon this using frequency separation [Burt & Adelson 1983], but still introduces edges where the inputs differ. Figure 1d illustrates typical results of our algorithm, which does a good job in the clouds and water in this case, but has a little trouble with the fog moving over the hills. Since the HDR images were not captured at the same moment, the fog, clouds, and water all moved between shots, and the sun continued to set, resulting in a slightly darker exposure on the left image, taken a minute after the right.

Visible artifacts in our method are due to an imperfect separation of perceptually important and unimportant details. It is difficult to know a priori which edge features should be regarded as salient and retained, and which would be better blended between adjacent images. We consider our current method a first cut at the problem of edge saliency, using a simple separation of the input into two frequency bands. While it may be difficult to arrive at a robust, high-level determination of feature saliency, we believe it is possible to minimize the appearance of artifacts by insuring that mismatches in the input are mapped to innocuous or visually confusing features in the output. Obfuscation is sometimes the most practical alternative to correctness.

[Burt & Adelson 1983]
P.J. Burt and E.H. Adelson, "A Multiresolution Spline with Application to Image Mosaics," *ACM Transactions on Graphics*, Oct 1983, 2(4), pp. 217-236.

[Pollefeys & Van Gool 2002]
M. Pollefeys and L. Van Gool, "From Images to 3D Models," *Communications of the ACM*, July 2002, 45(7), pp. 50-55.

[Sinha et al. 2004]
S. Sinha, M. Pollefeys, S.J. Kim, "High-Resolution Multiscale Panoramic Mosaics from Pan-Tilt-Zoom Cameras," *Proc. 4th Indian Conference on Computer Vision, Graphics and Image (ICVGIP 2004)*, pp. 28-33.