MaDCoW: Marginal Distortion Correction for Wide-Angle Photography with Arbitrary Objects

Supplementary Material

A. Calculating a linear perspective transform from the optical axis

Our goal is to derive a perspective projection $P(\mathbf{v})$ centered at the origin, with a given optical axis $\mathbf{v}_{opt}$. The rotation of the projection around the optical axis is not crucial, as we optimize for image-space rotation later. However, for initialization, we prefer to initialize with a preserved up-vector.

Let the input optical axis $\mathbf{v}_{opt}$ be defined as a direction on the view sphere, with longitude and latitude (λ, ϕ). Additionally, we want the principal point to project to specific image coordinates $\mathbf{p}_P$.

We first convert $\mathbf{v}_{opt}$ to Cartesian coordinates $\mathbf{c}$, where $\mathbf{c} = C(\mathbf{v}) = [\cos(\lambda)\cos(\phi), \sin(\lambda)\cos(\phi), \sin(\phi)]^T$. Then we construct the look-at matrix from the origin to $\mathbf{c}$, setting the up vector $\mathbf{u}$ arbitrarily to $[0, 1, 0]^T$, as

$$R = \begin{bmatrix} | & | & | \\ \frac{\mathbf{c}}{|\mathbf{c}|} & \frac{\mathbf{u}\times\mathbf{c}}{|\mathbf{u}\times\mathbf{c}|} & \frac{\mathbf{c}}{|\mathbf{c}|} \times \frac{\mathbf{u}\times\mathbf{c}}{|\mathbf{u}\times\mathbf{c}|} \\ | & | & | \end{bmatrix}. \tag{1}$$

Now, consider an arbitrary direction on the view sphere, $\mathbf{v}$. We define the linear perspective warp $P(\mathbf{v})$, for $\mathbf{v}_{opt}$, as

$$P(\mathbf{v}) = \frac{R^T C(\mathbf{v})}{C(\mathbf{v}) \cdot \frac{\mathbf{c}}{|\mathbf{c}|}} + \mathbf{p}_P. \tag{2}$$

B. User study design

We show an example pair of questions for a single scene that we present to the participants of our user study in Figure 1.

C. Full results and annotations

In Figure 2 we show Carroll et al. [1], Shih et al. [2], and our results, not covered by any insets, alongside the annotations we use for each.

D. Additional ablations

We show the effects of the exponential blending, initialization, and mesh coarseness in Figure C. Without exponential blending, the boundary between the object and the background appears distorted. If the initialization is chosen poorly, like choosing to initialize using the equirectangular projection, then the end result will have extreme distortions. Using a coarser mesh, in this case 64 by 64, than we have currently chosen for MaDCoW, 128 by 128, results in artifacts in the output. Additionally, we show that using the method of Shih et al. [2] to correct marginal distortion with masks that cover whole objects introduces visible curvature, as can be seen in Figure D.

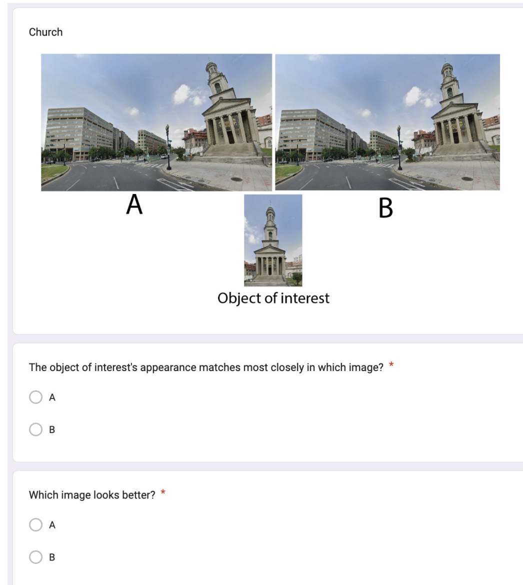

Figure 1. **Sample question from our user study.**

E. Algorithm summary

We present a summary of MaDCoW in Algorithm 1.

References

[1] Robert Carroll, Maneesh Agrawala, and Aseem Agarwala. Optimizing content-preserving projections for wide-angle images. *ACM Trans. Graph.*, 28(3), 2009. 1, 2

[2] YiChang Shih, Wei-Sheng Lai, and Chia-Kai Liang. Distortion-free wide-angle portraits on camera phones. *ACM Trans. Graph.*, 38(4), 2019. 1, 2, 3

(a) (b) (c) (d)

Figure 2. **Results and annotations.** In each row, (a) shows the line annotations used for the (Carroll et al. [1]) results except for the second row, which shows face detection annotations use for (Shih et al. [2]). (b) shows the results of (Carroll et al. [1]) in each row except for the second, which shows the result of (Shih et al. [2]). (c) shows the annotations used for MaDCoW and (d) shows the results of our method. Red lines denote line constraints, green regions denote DVC constraints, and the red dots denote the principal points optimized using our method.

Figure C. **Ablations:** (a) Our result. (b) No exponential blending (c) Equirectangular initialization. (d) Coarser mesh.

Figure D. **Ablations:** (a) Our result. (b) Stereographic projection (Shih et al. [2]) for the people on the left and right sides, which distorts their shapes.

Algorithm 1 Multi-Region Distortion Correction

Require: Image I, regions $\{W_k\}_{k=1}^{K}$, line annotations
Ensure: Corrected image I'
for $k = 1$ to K **do**
    Initialize T_k so that its center of projection is midway between the center of the image and the center of the object mask on the viewing sphere
    Optimize T_k to minimize E_c (Eq. 2) using Newton's Method
end for
$P_{sg} \leftarrow$ stereographic projection of I
for each vertex (i, j) **do**
    if $(i, j) \in W_k$ for any k **then**
        $\mathbf{p}_{i,j} \leftarrow T_k(\mathbf{v}_{i,j})$
    else
        $T'_k \leftarrow$ blend T_k and P_{sg} (Eq. 8)
        $\mathbf{p}_{i,j} \leftarrow T'_k(\mathbf{v}_{i,j})$
    end if
end for
Optimize $\{\mathbf{p}_{i,j}\}$ to minimize $w_l E_l + w_c E_c + w_s E_s + w_{DVC} E_{DVC}$ using LBFGS
Warp I to get I' by bilinearly interpolating $\mathbf{p}_{i,j}$ over $\mathbf{v}_{i,j}$.
return I'
