13th International Conference on Computer Vision (ICCV 2011), November 6-13, 2011, Barcelona, Spain

This project was supported in part by Nokia and by NSF grant number 0535236.

What Characterizes a Shadow Boundary under the Sun and Sky?

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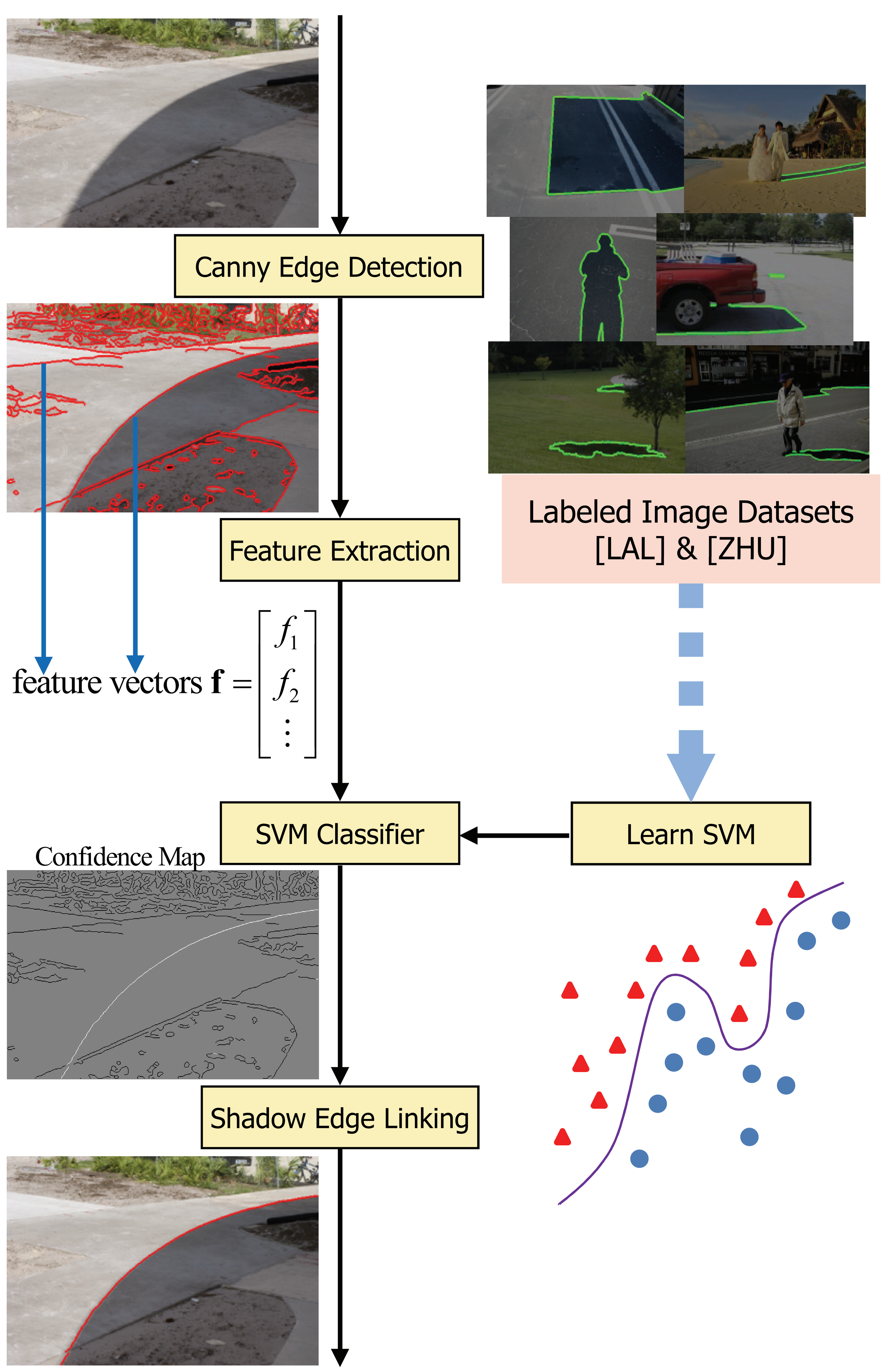
Key Contributions

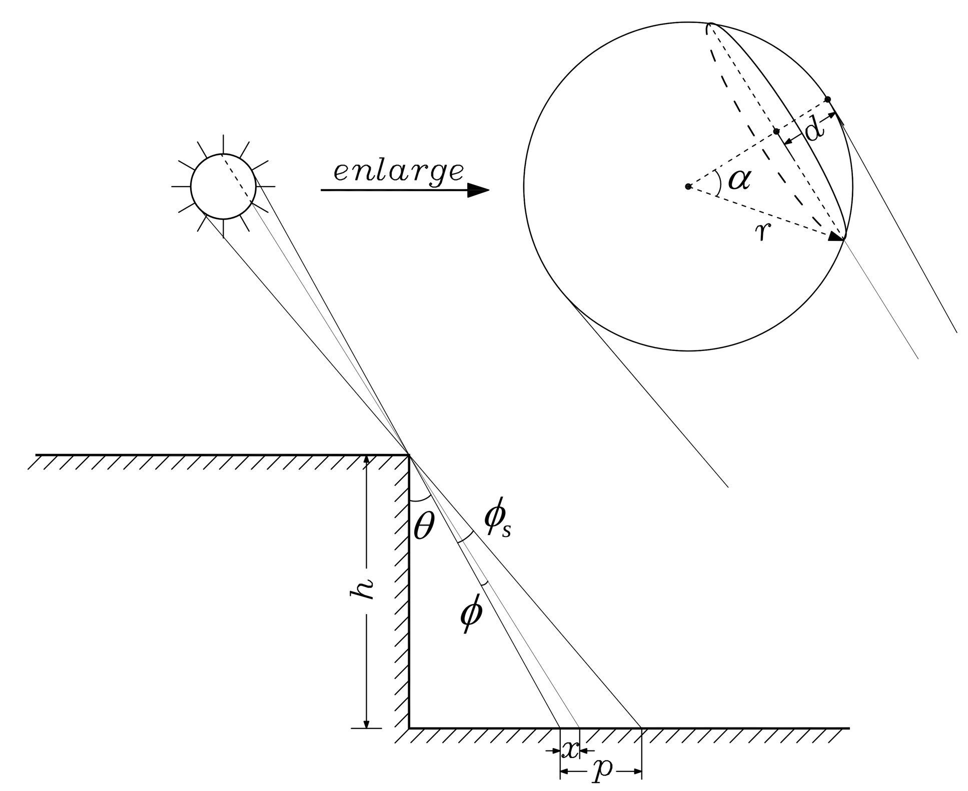
- ▶ A careful analysis of the physical models of shadows under the sun and the sky;
- ▶ A compact set of robust visual features motivated from these physical models for shadow boundary detection;
- ▶ A end-to-end shadow boundary detection system built upon these features, which outperforms previous methods.

Our Shadow Detection System

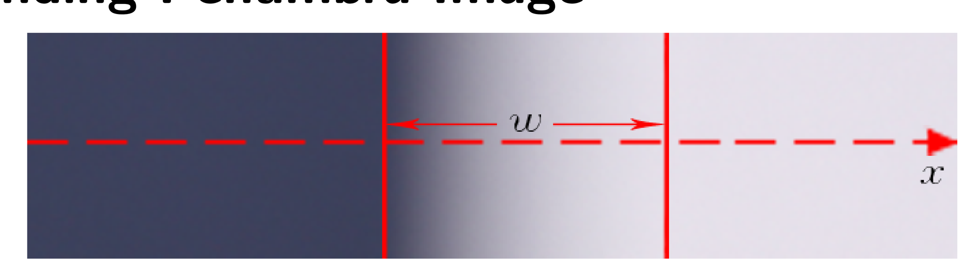


New Features: Outdoor Shadow Physical Models

▶ Shadow caused by the Sun occlusion

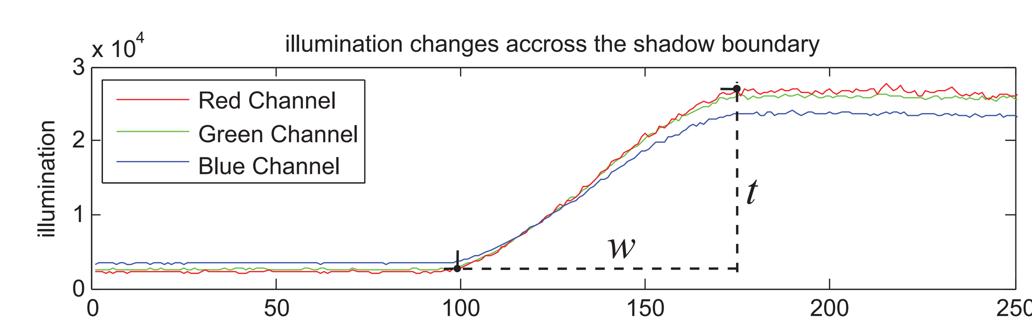


▶ Corresponding Penumbra Image



▶ Compute Penumbra Width, Shape and Color

- Penumbra width proportional to occluder height: $\frac{h}{cos^2\theta}$
- Similar shape for all penumbra widths (soft or sharp shadow): illumination change rate proportional to $\sqrt{1-(\frac{2x}{w})^2}$, $-\frac{w}{2} \le x \le \frac{w}{2}$.
- Color shifts from bluish sky to reddish sun



▶ Visual features Motivated from Physical Models

- Shadow sharpness w in RGB channels
- Dark-to-bright slope
- Dark-to-bright ratio: Sky vs. Sun
- Dark-to-bright gradient direction mismatch

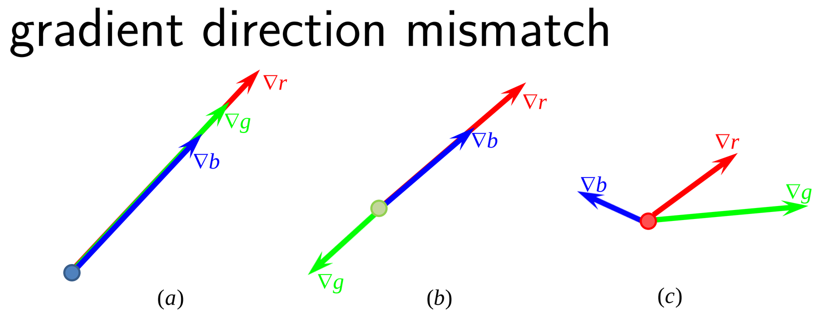


Figure: Gradient of shadow edges: same direction in R, G, B in (a). Reflectance, silhouette & other edges: any direction in (a) (b) (c).

Experiments

▶ Dataset and Settings:

- Two datasets: [LAL] (135 images, 100 training, 35 testing) and [ZHU] (162 images, 100 training, 62 testing)
- Feature Vector: 12 features, each at three scales
- Classifier: SVM with RBF kernel (also compared with AdaBoost)

▶ Quantitative Comparison

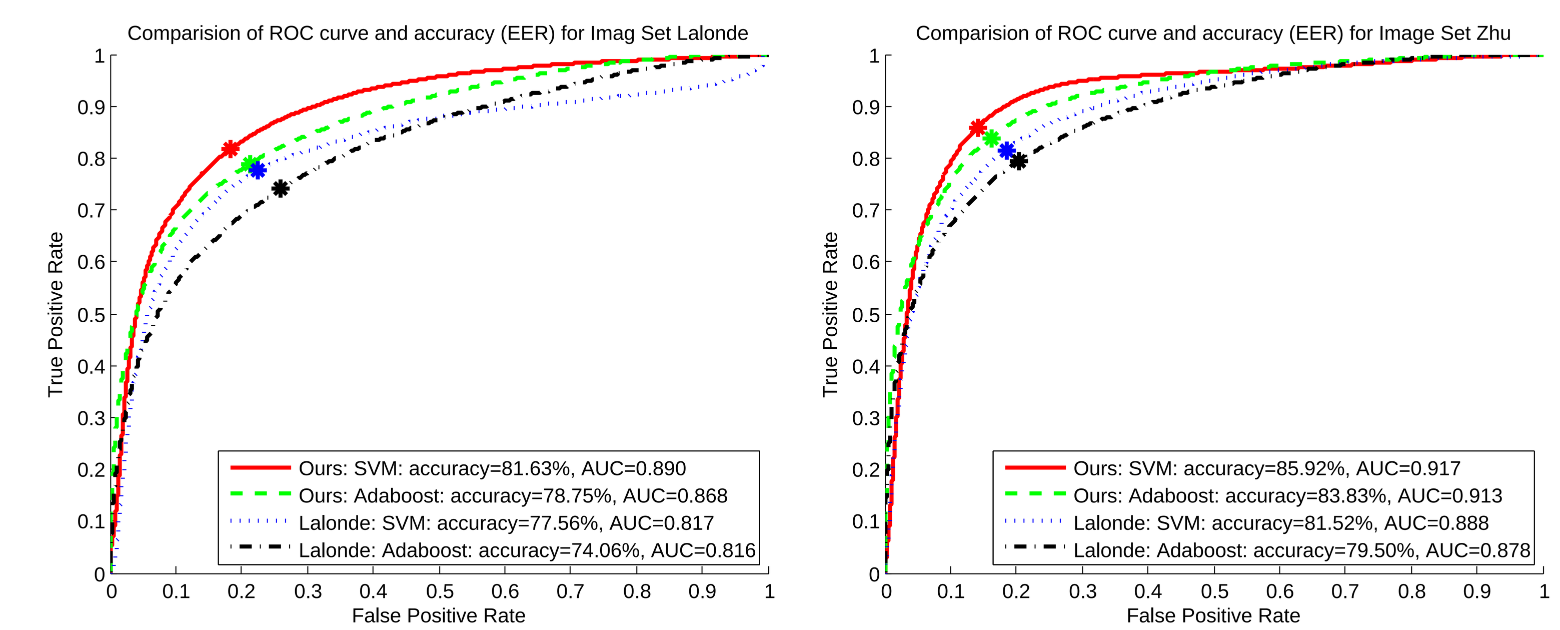


Figure: ROC curves on dataset LAL and Zhu.

Dataset	AdaBoost		SVM	
	Ours	Lalonde's	Ours	Lalonde's
LAL	78.75%	74.06%	81.63%	77.56%
ZHU	83.83%	79.50%	85.92%	81.52%

Table: Accuracy at equal error rate, compared with [LAL] in dataset [LAL] and [ZHU].

▶ Qualitative Comparison

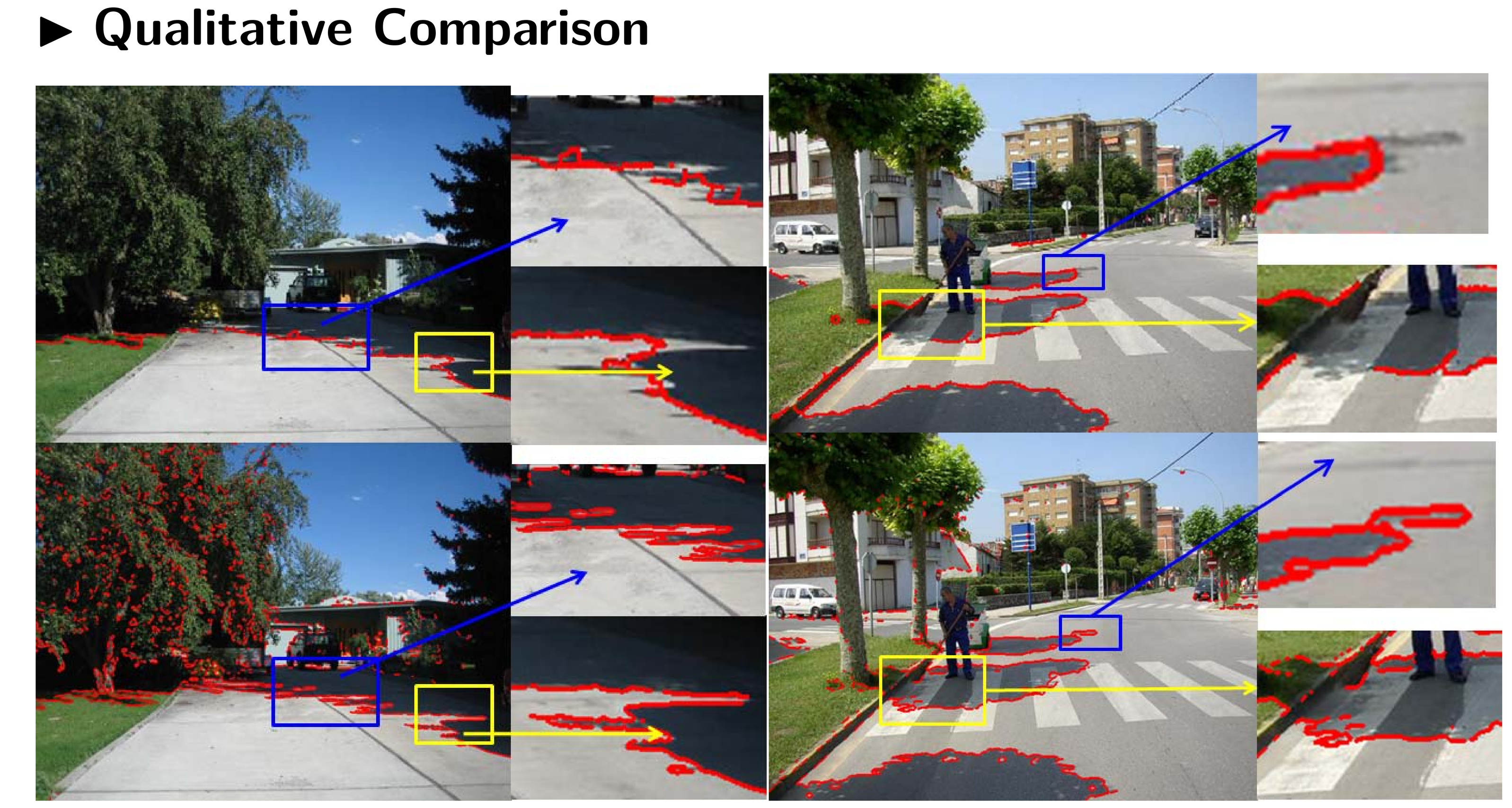


Figure: Shadow labeled with red color. Compare ours (bottom) with [LAL] (top).

[LAL] J.-F. Lalonde, A. A. Efros, and S. G. Narasimhan, "Detecting ground shadows in outdoor consumer photographs," In *Proc. ECCV*, 2010, pp. 1–14.
[ZHU] J. Zhu, K. Samuel, S. Masood, and M. Tappen, "Learning to Recognize Shadows in Monochromatic Natural Images," In *Proc. CVPR*, 2010, pp. 223–230.