Image Quality Assessment for Photo-consistency Evaluation on Planar Classification in Urban Scenes

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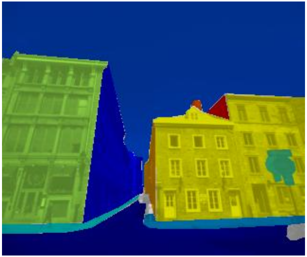
Context

Set of calibrated images



Semantic ground truth

Main goal - Semantic segmentation

Context

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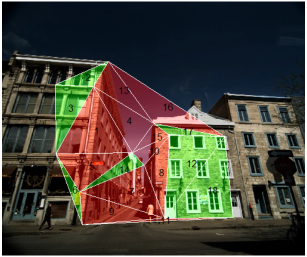

Flatness ground truth

Main goal - Semantic segmentation
Paper issue - Relation between surface flatness and photo-consistency measure

Intermediate Features

Intermediate features

Aim - SuperPixels (SP) photometrically coherent on multiview

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Intermediate goal - Planar classification for triangular mesh (P/NP)

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Idea

Integration of the geometrical information in SP constructor

Photo-consistency Measure for P/NP Classification

- **Inputs -** Calibrated multiview images and sparse 3D point cloud
- **Hypothesis -** Piecewise planar smooth surfaces
- **Tools -**
  - Homography estimation
  - Photo-consistency

Photo-consistency Measure for P/NP Classification

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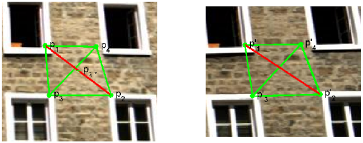
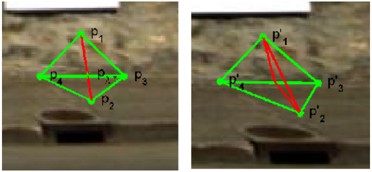


Planar case - high similarity



Non-planar case - low similarity

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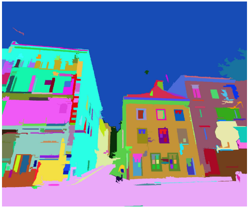
State-of-the-Art

- Single view approaches
  - SP over-segmentation method

    [Felzenszwalb and Huttenlocher, 2004]
  - Geometry as a prior knowledge

    [Hoiem et al., 2008]

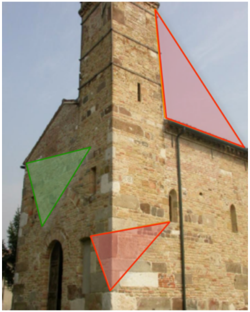


State-of-the-Art

- Multiview approaches
  - Piecewise planar assumption

    [Gallup et al., 2010]
  - Photo-consistency constraint

    [Toldo and Fusiello, 2010]



Motivations

- Intermediate features
- Geometry and planar surfaces
- Photo-consistency

$\Rightarrow$ Evaluation protocol for photo-consistency measures

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Photo-Consistency Measures

Definition

Photo-Consistency Measure or **Image Quality Assessment (IQA)** quantification of photometrical similarity between a reference region z and a target region $\tilde{z}$

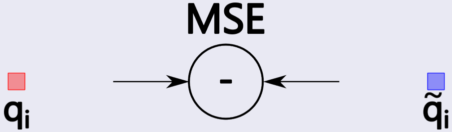
Analysis of two types of measures:

- Euclidean Distance-based Measures
- Cosine Angle Distance-based Measures

Euclidean Distance-based Measures

- N number of pixels in z and $\tilde{z}$
- v_i color value of the pixel q_i in the reference image
- $\tilde{v}_i$ color value of the pixel $\tilde{q}_i$ in the warped image
- r size of the neighbourhood used

Mean Square Error

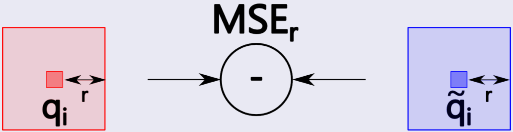


$$\mathrm{MSE}(\mathbf{z}, \tilde{\mathbf{z}}) = \frac{1}{N} \sum_i (v_i - \tilde{v}_i)^2$$

Euclidean Distance-based Measures

- N number of pixels in z and $\widetilde{z}$
- v_i color value of the pixel q_i in the reference image
- $\widetilde{v}_i$ color value of the pixel $\widetilde{q}_i$ in the warped image
- r size of the neighbourhood used

Generalised MSE

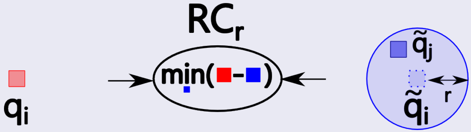


$$\mathrm{MSE}_r(\mathbf{z}, \widetilde{\mathbf{z}}) = \frac{1}{N} \sum_i \left[\frac{1}{(2r)^2} \sum_{j \,/\, |q_i - q_j| \leqslant r} (v_j - \widetilde{v}_j)^2\right]$$

Euclidean Distance-based Measures

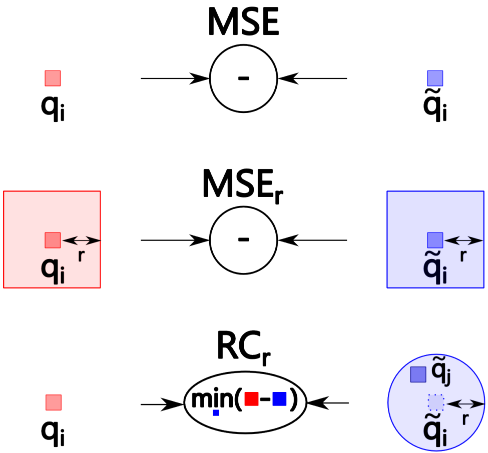
- N number of pixels in z and $\widetilde{z}$
- v_i color value of the pixel q_i in the reference image
- $\widetilde{v}_i$ color value of the pixel $\widetilde{q}_i$ in the warped image
- r size of the neighbourhood used

r-Consistency [Kutulakos, 2000]



$$\mathrm{RC}_r(\mathbf{z},\widetilde{\mathbf{z}}) = \frac{1}{N}\sum_i \left(\min_{j \,/\, (q_i - q_j)^2 < r^2} |v_i - \widetilde{v}_j| \right)^2$$

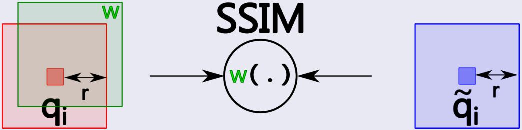
Euclidean Distance-based Measures



Cosine Angle Distance-based Measures

- $\mu_{\mathbf{z}}$ (resp. $\mu_{\tilde{\mathbf{z}}}$) the mean of v_i (resp. $\tilde{v}_i$) on z (resp. $\tilde{z}$)
- $\sigma_{\mathbf{z}}$ (resp. $\sigma_{\tilde{\mathbf{z}}}$) the standard deviation of v_i (resp. $\tilde{v}_i$)
- $\sigma_{\mathbf{z}\tilde{\mathbf{z}}}$ the covariance of z and $\tilde{\mathbf{z}}$

Structural SImilarity Measure [Wang et al., 2004]



$$\begin{aligned}\mathrm{SSIM}(\mathbf{z},\tilde{\mathbf{z}}) &= l(\mathbf{z},\tilde{\mathbf{z}}).c(\mathbf{z},\tilde{\mathbf{z}}).s(\mathbf{z},\tilde{\mathbf{z}}) \\ &= \frac{2\mu_{\mathbf{z}}\mu_{\tilde{\mathbf{z}}}+\alpha}{\mu_{\mathbf{z}}^2+\mu_{\tilde{\mathbf{z}}}^2+\alpha}\cdot\frac{2\sigma_{\mathbf{z}}\sigma_{\tilde{\mathbf{z}}}+\beta}{\sigma_{\mathbf{z}}^2+\sigma_{\tilde{\mathbf{z}}}^2+\beta}\cdot\frac{\sigma_{\mathbf{z}\tilde{\mathbf{z}}}+\gamma}{\sigma_{\mathbf{z}}\sigma_{\tilde{\mathbf{z}}}+\gamma}\end{aligned}$$

Cosine Angle Distance-based Measures

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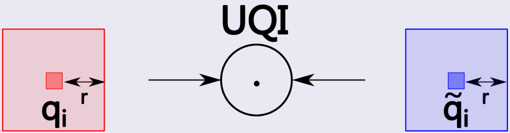
Universal Quality Image [Z. Wang and Bovik, 2002]



$$\mathrm{UQI}(\mathbf{z}, \tilde{\mathbf{z}}) = \frac{4\sigma_{\mathbf{z}\tilde{\mathbf{z}}}\, \mu_{\mathbf{z}}\mu_{\tilde{\mathbf{z}}}}{(\sigma_{\mathbf{z}}^2 + \sigma_{\tilde{\mathbf{z}}}^2)\ [\mu_{\mathbf{z}}^2 + \mu_{\tilde{\mathbf{z}}}^2]}$$

Cosine Angle Distance-based Measures

- $\mu_{\mathbf{z}}$ (resp. $\mu_{\tilde{\mathbf{z}}}$) the mean of v_i (resp. $\tilde{v}_i$) on z (resp. $\tilde{z}$)
- $\sigma_{\mathbf{z}}$ (resp. $\sigma_{\tilde{\mathbf{z}}}$) the standard deviation of v_i (resp. $\tilde{v}_i$)
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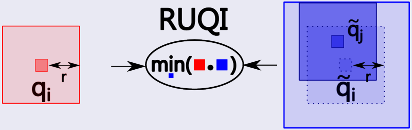
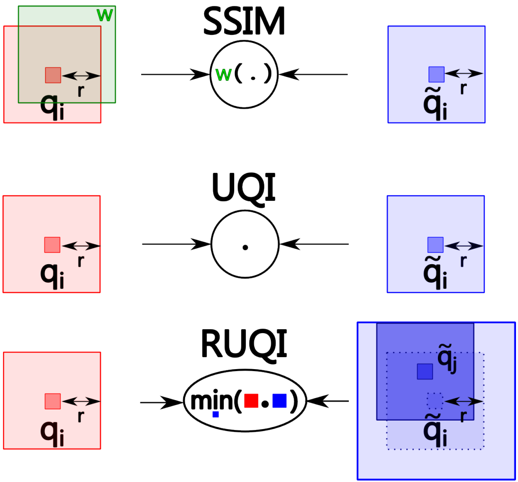
RUQI (Proposed measure)



$$\mathrm{RUQI}(\mathbf{z},\tilde{\mathbf{z}}) = \frac{1}{N}\sum_i \left(\max_{j \,/\, (q_i - q_j)^2 < r^2} (\mathrm{UQI}(\xi_i, \tilde{\xi}_j)) \right)$$

Cosine Angle Distance-based Measures



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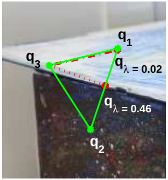
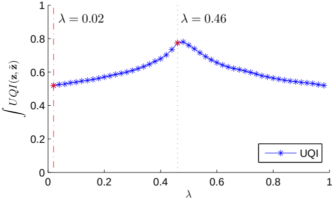
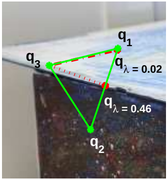
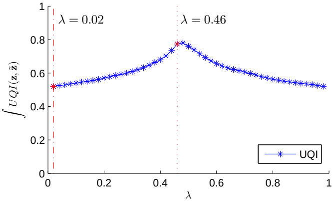
IQA Protocol Evaluation

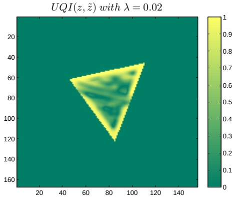


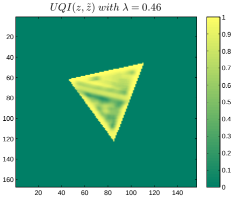


IQA Protocol Evaluation









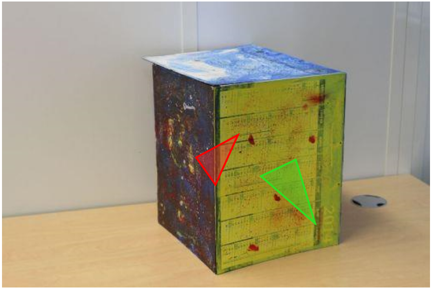
Non-planar triangle: Variation of IQA with different λ

Algorithm

1. Estimation of right value $\lambda^{\star}$
2. Estimation of homographies
3. For each $\lambda \in [0, 1]$
   1. Estimation of the warped image depending on λ
   2. Computation of the IQA value
4. Classification in P/NP region based on the IQA value

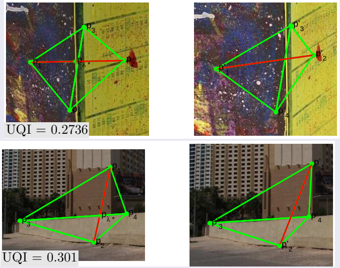
Experiment

Input data - Real data with controlled and uncontrolled lighting
Tests - 6 measures on 87 triangles (58% NP)

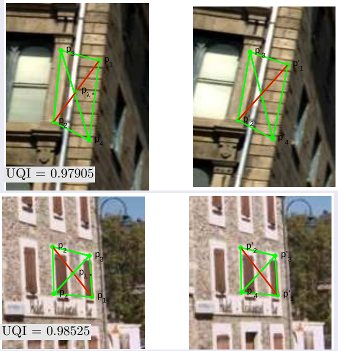


Results (1)

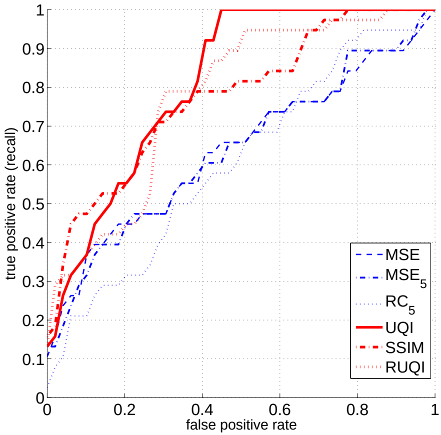
Non-planar zones



Planar zones

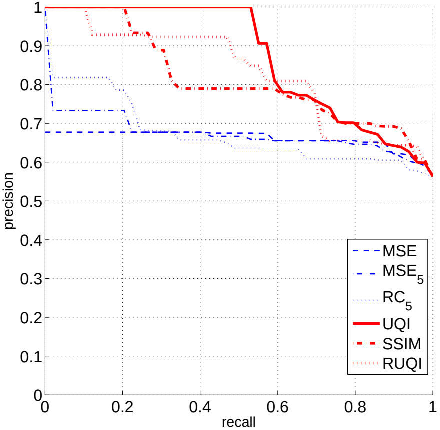


Results (2)



Receiver Operator Characteristic (ROC) curve

Results (3)



Precision-Recall (PR) curve

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Overview

Contributions

- IQA protocol evaluation for P/NP classification
- 'SSIM' more efficient than 'MSE'
- UQI overcomes all measures

Future work

- IQA integration in SP constructor
- Cut non-planar zone

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Test \ GT	1	0	
1	TP	FP	Pr
0	FN	TN	NPr
	R	NR FPR	

Binary classification evaluation