Subjective and Objective Quality Assessment of Stitched Images for Virtual Reality

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Thesis Defense

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Outline of the Talk

1. Introduction
   - Problem Definition
   - Challenges
   - Prior Work
2. Thesis Overview
   - Database and Subjective Quality Assessment
   - Automatic Quality Assessment Algorithm
3. Experiments and Results
4. Conclusion and Future Work

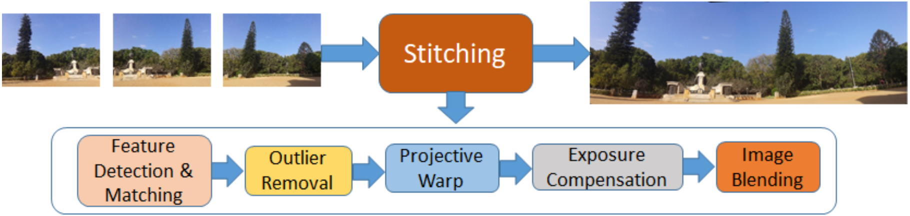
Outline of the Talk

Introduction

- Virtual Reality (VR) - immersive experience through wide field of view images/videos
- VR applications - motion pictures, cinematic VR, immersive storytelling etc.
- Head mounted displays (HMD) - freedom to choose desired views
- Wide field of view images - stitching multiple images with overlapping views

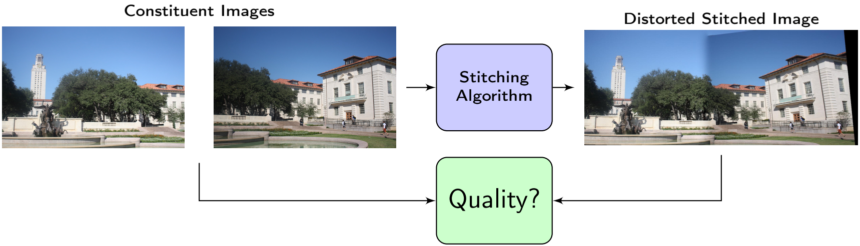
Introduction

- Stitching algorithm - multiple stages
  - Each stage - influence on quality of stitched image



- VR popularity - necessity for quality control
- **Relevance** - benchmark, tune parameters and compare various stitching algorithms.

Problem Statement



Challenges

- Development of quality index - captures stitching induced distortions
  - Ghosting and blur - inaccurate matching of feature points

Ghosting

Blur

Color Distortion

Geometric

Challenges

Ghosting

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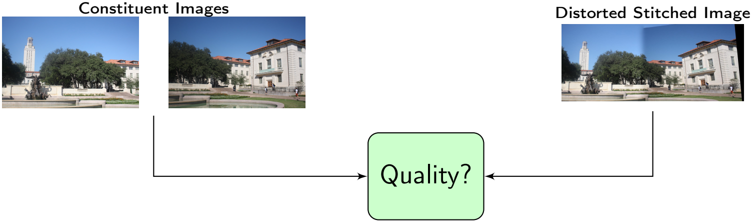
Geometric

- Stitching induced distortions - specific to stitched images

Challenges

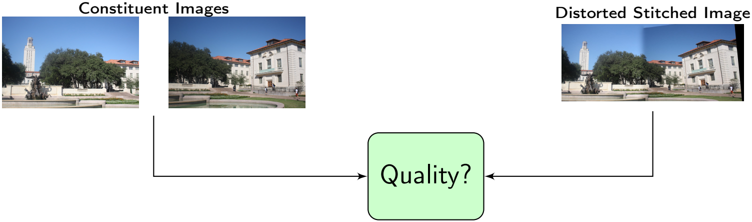
- Absence of reference stitched images - not full reference quality assessment



Problem Setup

Challenges

- Absence of reference stitched images - not full reference quality assessment
- Constituent images - reference information



Problem Setup

Problem Setup - Assumption

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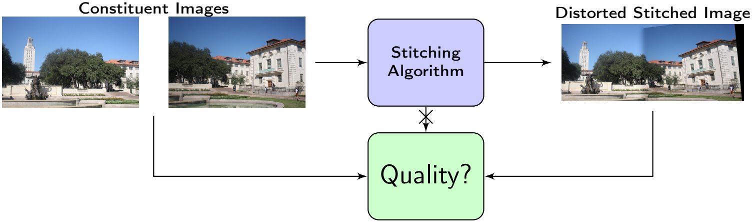
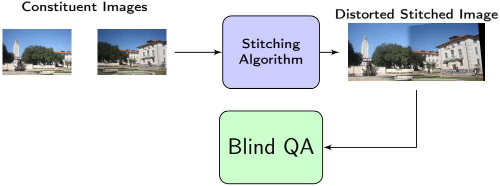


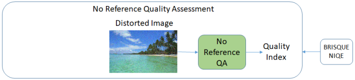
Problem Setup

Assumptions - access to individual and stitched images, no knowledge of stitching algorithm

Prior Art - No Reference Quality Assessment (QA)

- No Reference (NR) quality assessment - rich literature and widely studied
- Natural Scene Statistics (NSS) - DIIVINE[Moorthy2011], BRISQUE [Mittal2012], NIQE [Mittal2013]

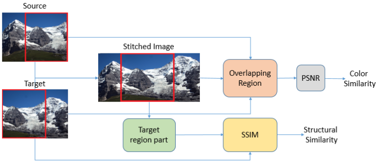




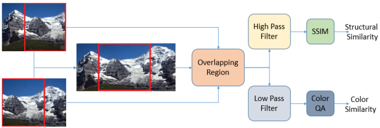
- Existing QA - do not address types of distortions observed in stitched images

Prior Art - QA in Stitched Images

- [WeiXu2010] - evaluates color similarity and structural similarity
  - Restrictive model - uses pointwise comparison, can be inaccurate
- [Qureshi2012] - computes color and structural similarity in overlapping regions
  - Extension of [WeiXu2010] - uses high pass content in overlapping region for structural similarity
- Above algorithms - not evaluated on subjective database



[WeiXu2010] method



[Qureshi2012] method

Contributions

- Stitched image quality assessment database
  - Stitched images captured across diverse scenes
  - Subjective evaluation - perception of distortions
- Objective quality assessment
  - Natural scene statistics model
    - Bivariate statistics - increased correlations due to distortions
  - Correlates well with human perception

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Dataset

- Stitched image quality assessment database
  - Images from 26 scenes - buildings, gardens, indoor and public places
  - 264 stitched images - fusing multiple views with overlapping regions
  - Static scenes - no object motion

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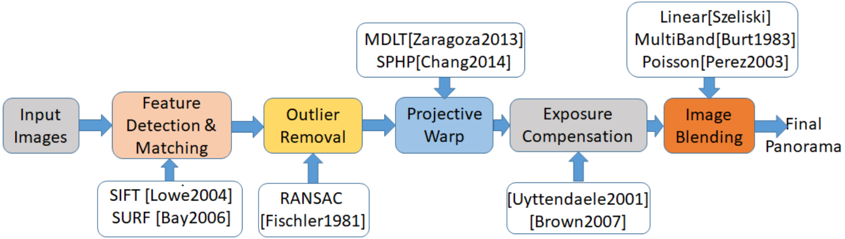
  - Parameter options associated with each block



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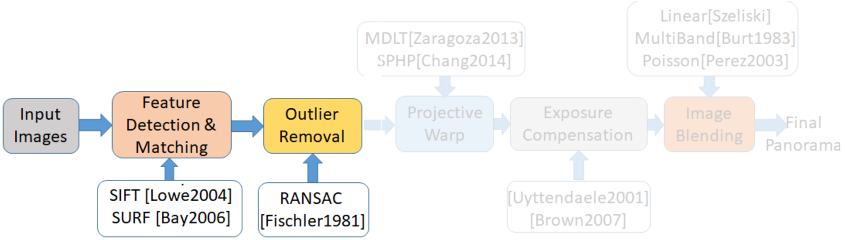

Feature Detection, Matching and Outlier Removal

- Image alignment - detecting keypoints in overlapping regions
  - Detection and matching- SIFT
  - Outlier removal - Random Sample Consensus

Figure: Keypoint Detection

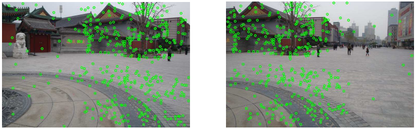

Figure: Keypoint Matching

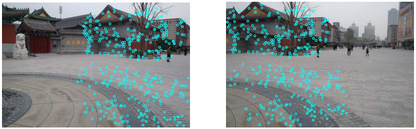

Figure: Outlier removal

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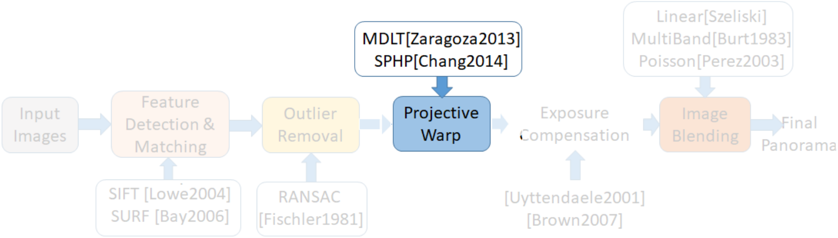
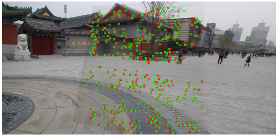


Homography and Image Warping

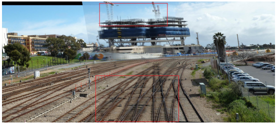
- Warp - transformation on co-ordinates for aligning overlapping regions
  - Homography - generalized transform, Direct Linear Transform (DLT)
  - Moving DLT [Zaragoza2013] (MDLT) - patch level homography
  - Shape preserving warp (SPHP) [Chang2014] - constrained homography



Homography

MDLT

SPHP



Homography

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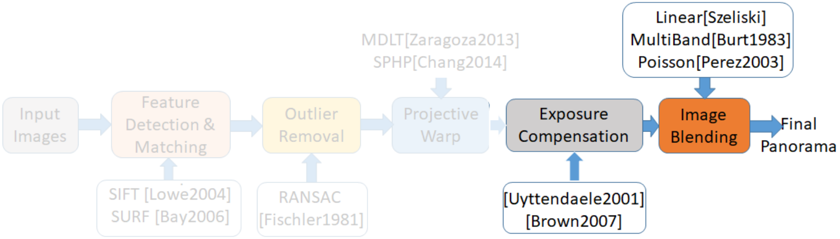
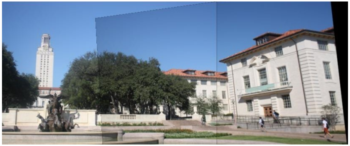


Image Blending

- Blending - fusing multiple images to form single composite image
  - Smooth transition with no visible seams
- Feathering - weighted averaging
- Multiband - Laplacian pyramid based blending
- Poisson - gradient domain, optimizing the cost function



No Blending

Multiband

Feathering with exposure compensation

Poisson

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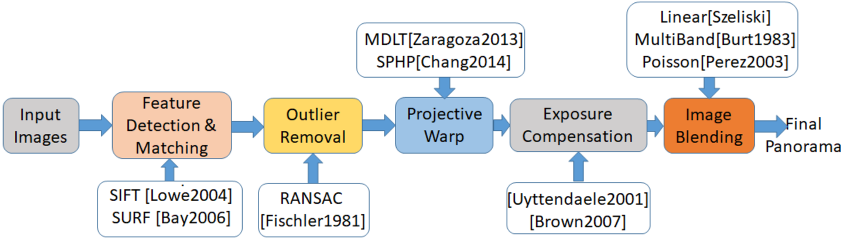
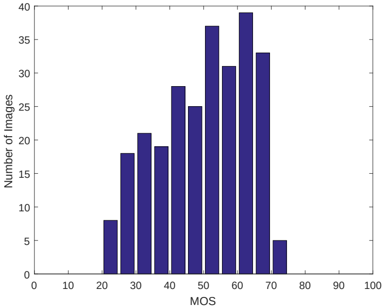


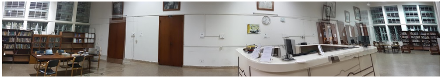
- Major impairments - ghosting, blur, geometric and color

Subjective Study

- Single stimulus continuous quality assessment
- Rating - viewing images on a VR head mounted device (HMD)
- Images rated by 35 subjects across 3 sessions
- Processing of scores - Mean Opinion Score (MOS) for each image after rejecting outliers



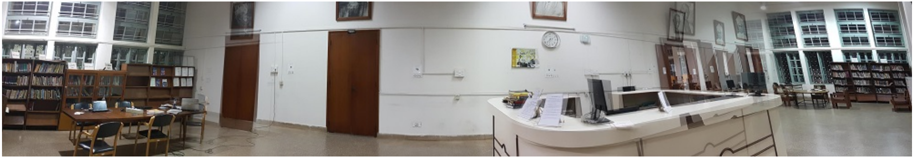
Distribution of MOS



$MOS = 21.546$

$MOS = 65.238$

Subjective Study



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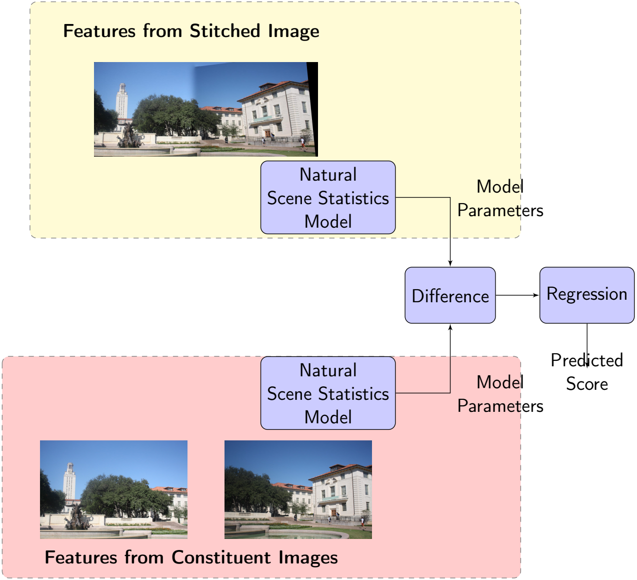
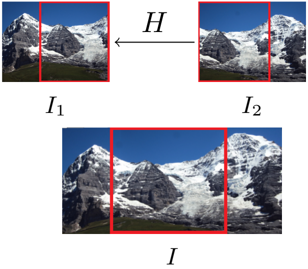
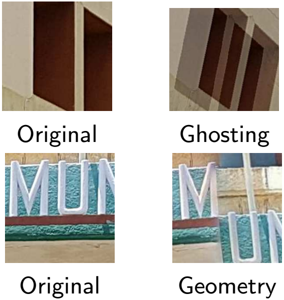
Outline of the Talk

Stitched Image Quality Evaluator (SIQE) Framework



Origin of Distortions

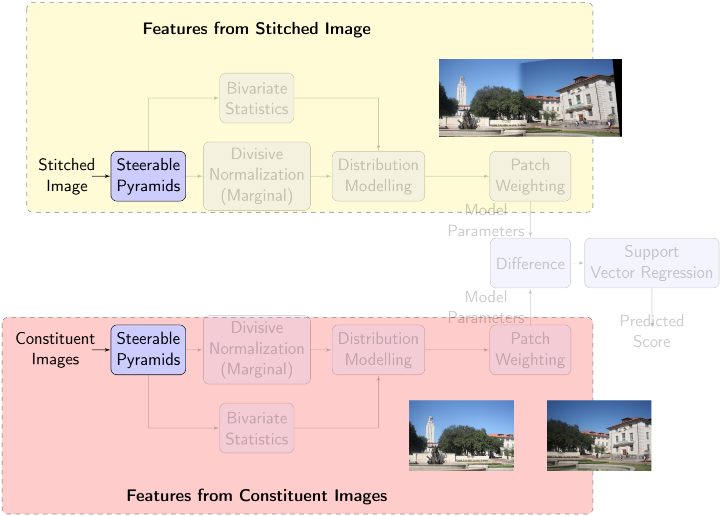




$$I(x) = (1 - \alpha(x))I_1(x) + \alpha(x)I_2(Hx), \quad \text{where } \alpha(x) \in (0, 1)$$

- $I_1(x) \neq I_2(Hx)$ - combination of ghosting and blur
  - Presence of additional edges
  - Increased spatial correlation
- Geometric distortion - presence of extraneous edges

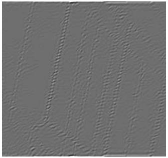
Multi-Orientation Decomposition

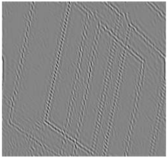


Multi-Orientation Decomposition

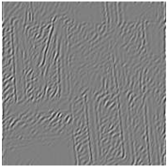
- Structural artifacts from ghosting and geometric - orientation dependent
- Steerable pyramid decomposition - 6 orientations, 2 scales for each $N \times N$ patch

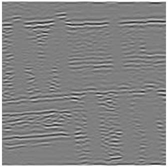

Ghosting


$s_1^{60^\circ}$

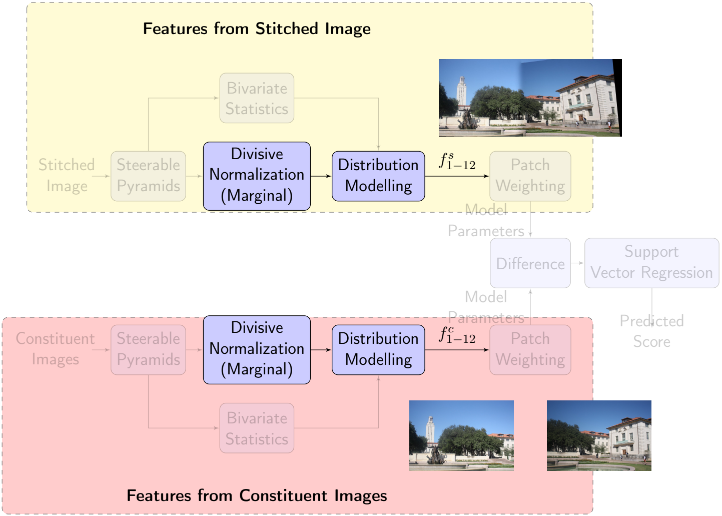

$s_1^{150^\circ}$


Geometry


$s_1^{30^\circ}$


$s_1^{90^\circ}$

Divisive Normalization



Divisive Normalization

- Divisive Normalization - $\hat{y} = y/p$ for subband coefficient y, with $p = \sqrt{Y^T C_U^{-1} Y / N}$ where C_U is the covariance of neighborhood around y, N - number of neighbors
  - Contrast masking
  - Reduce statistical dependencies - decorrelation
- Previously shown to capture blur in [Li2009], [Moorthy2011]
- Besides blur, captures edges introduced due to distortions
  - Normalization factor p - measure of local variance
  - p - higher values near edges

Divisive Normalization - Modeling

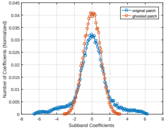
- Ghosting and geometric distortions - presence of additional edges
  - Distribution of distorted patch - higher peak value at zero as $\hat{y} = y/p$
- Model - Generalized Gaussian Distribution (GGD)
- Features - GGD shape parameters


Original

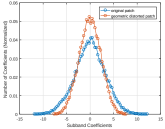

Ghosting


Original


Geometry

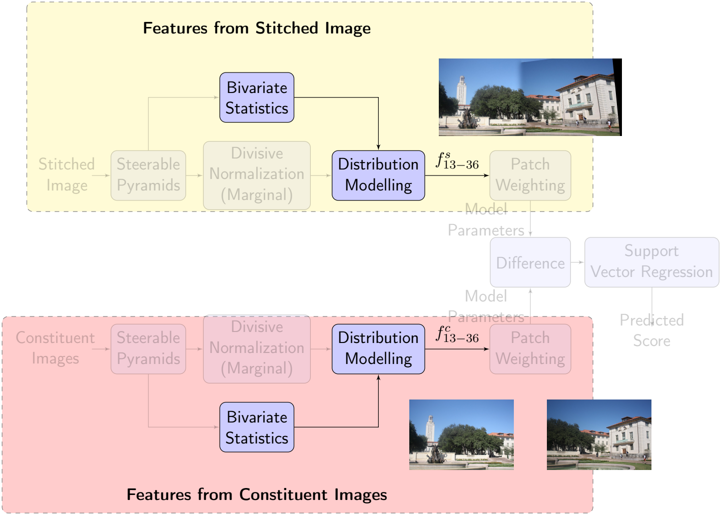


$P(d_1^{150^\circ}(x, y)$



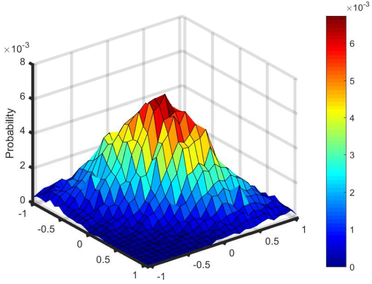
$P(d_1^{30^\circ}(x, y))$

Bivariate Model

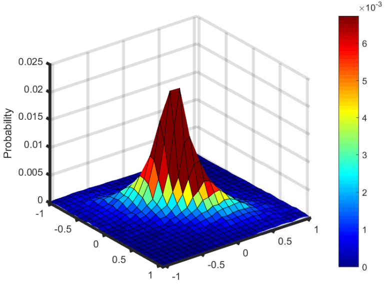


Bivariate Model

- Capturing increased spatial correlation in ghosting - bivariate distribution
- Bivariate statistics - adjacent subband coefficients $P(s_\alpha^\theta(x,y), s_\alpha^\theta(x+1,y))$ (with no divisive normalization)
- Distribution of ghosted patch - higher peak value than undistorted distribution



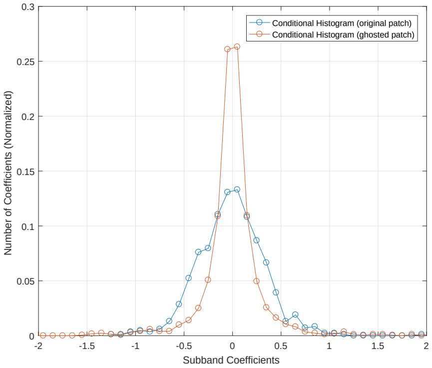
Original Patch



Ghosted Patch

Bivariate Model - Conditional Distribution Interpretation

- Conditional Statistics - $P(s_\alpha^\theta(x+1,y)/s_\alpha^\theta(x,y) \in (-\delta,\delta))$



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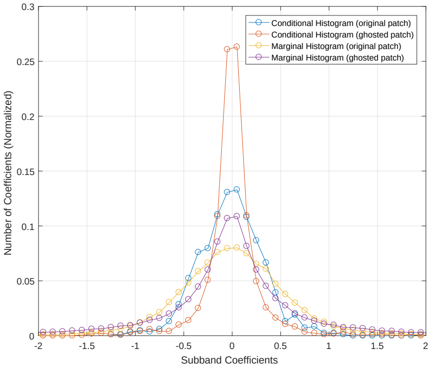


- Deviation between conditional distributions - higher than marginal distributions

Bivariate Model - GMM and BGGD

- Previous approaches - Bivariate GGD - let $s_\alpha^\theta(x+1,y) = a$, $s_\alpha^\theta(x,y) = b$, $z = [a,b]^T$

$$f(z) = K \exp\left(-(z^T \mathbf{M}^{-1} z)^\beta\right)$$

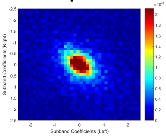
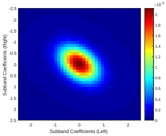
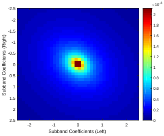
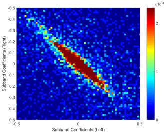
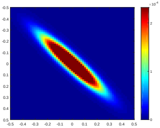
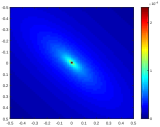
- Bivariate Gaussian (BVG) - BGGD with $\beta = 1$
- Our method - Gaussian mixture model

$$f(a,b) = \sum_{i=1}^{M} \omega_i \mathcal{N}(\mathbf{0}, \Sigma_i)$$

  - Components - zero mean, distribution modeled by ω_i, Σ_i
  - Parameter estimation - Expectation Maximization (EM) algorithm
  - GMM - QA

Bivariate Model - Model Comparison

- Model comparisons - GMM and BGGD

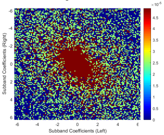
	Empirical	GMM	BGGD
 Pristine		 (KL - 0.1477)	 (KL - 0.2167)
 Distorted		 (KL - 0.1547)	 (KL - 0.24)

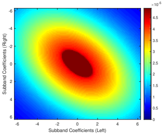
Bivariate Model - Model Comparison

- Model comparisons - GMM and BVG

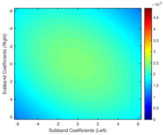
Empirical GMM BVG

Pristine



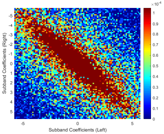


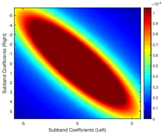
(KL - 0.1535)



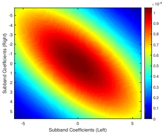
(KL - 0.4635)

Distorted





(KL - 0.1547)



(KL - 0.3823)

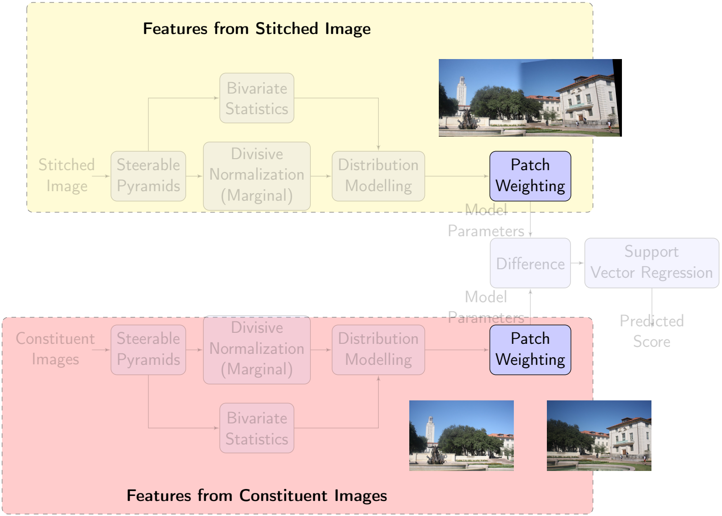
Bivariate Model - Features

- For $s^{\theta}_{\alpha}(x+1,y) = a$, $s^{\theta}_{\alpha}(x,y) = b$

$$f(a,b) = \sum_{i=1}^{M} \omega_i \mathcal{N}(\mathbf{0}, \Sigma_i)$$

- Covariance $C = \sum_{i=1}^{M} \omega_i \Sigma_i$, eigen values of C as features
    - Horizontal - $s^{\theta}_{\alpha}(x+1,y) = a$, $s^{\theta}_{\alpha}(x,y) = b$
    - Vertical - $s^{\theta}_{\alpha}(x,y+1) = a$, $s^{\theta}_{\alpha}(x,y) = b$

Patch Weighting



Patch Weighting

- All patches equal contribution?

$e = 0.957$

$e = 0.459$

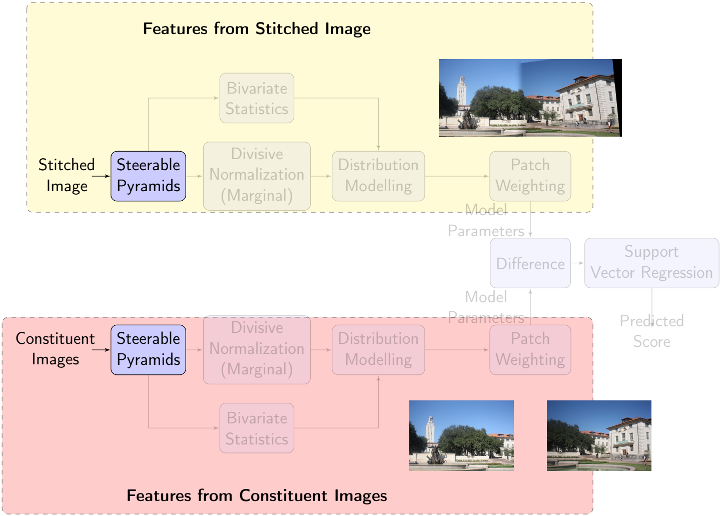
$e = 0.354$

$e = 0.106$

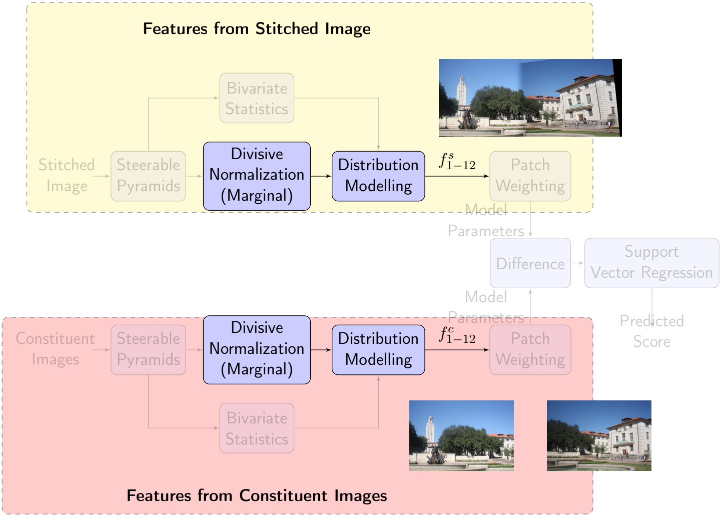
- Ghosting and blur artifacts - not perceived in smooth regions
- Gray level co-occurrence matrix (GLCM) [Haralick1973]
- Energy values of GLCM, $e \in [0, 1]$, with $e = 1$ for constant image
- Patch weight $w = 1 - e$
- Textured patches - equal weights through non-linearity

$$g(w) = 1 - \exp\left(-\left(\frac{w}{\sigma}\right)^2\right)$$

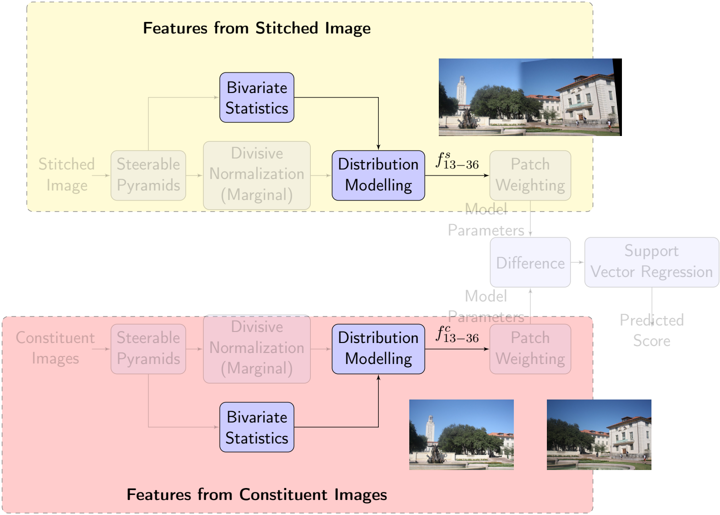
Model Summary



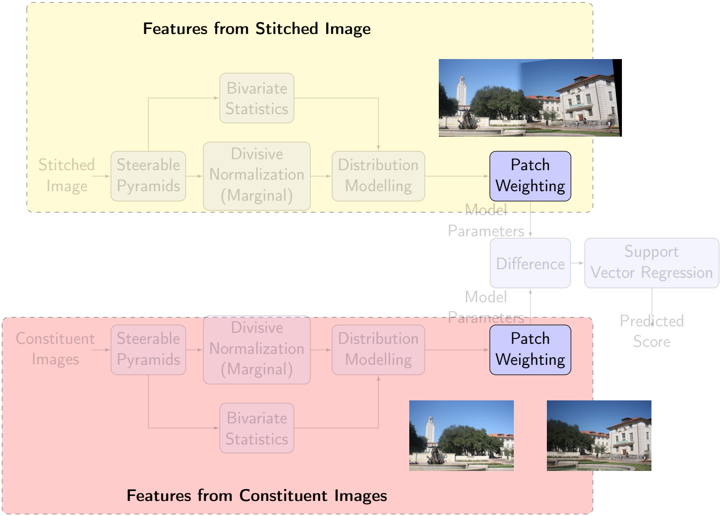
Model Summary



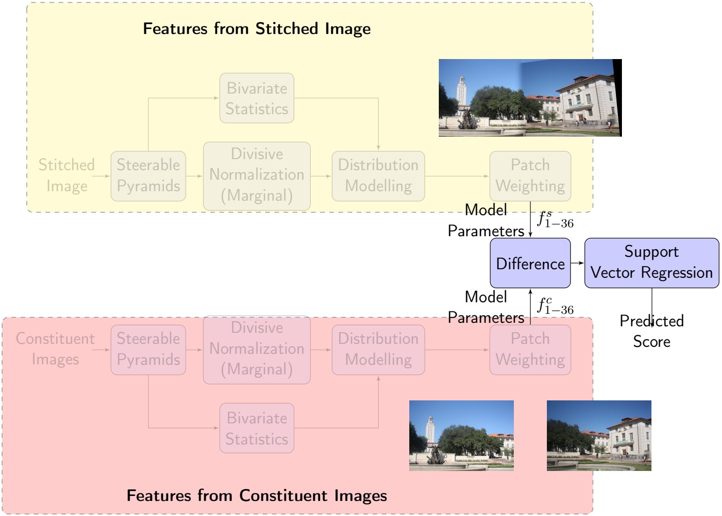
Model Summary



Model Summary



Prediction


Features from Stitched Image
Bivariate Statistics
Stitched Image
Steerable Pyramids
Divisive Normalization (Marginal)
Distribution Modelling
Patch Weighting
Model Parameters
f^s_{1-36}
Difference
Support Vector Regression
Model Parameters
f^c_{1-36}
Predicted Score
Constituent Images
Steerable Pyramids
Divisive Normalization (Marginal)
Distribution Modelling
Patch Weighting
Bivariate Statistics
Features from Constituent Images

Outline of the Talk

Correlation with Human Judgments

- Database - 80% training and 20% testing with non overlap of scenes
- Performance metric - Spearman rank order correlation coefficient (SROCC) and Pearson's linear correlation coefficient (LCC)
- Median performance value - 1000 random train-test combinations
- Performance comparison - NR QA metrics BRISQUE [Mittal2012], NIQE [Mittal2012], DIIVINE [Moorthy2011]

	SROCC	LCC
BRISQUE (trained on our database)	0.6224	0.5914
NIQE	0.1524	0.1051
DIIVINE (trained on our database)	0.5706	0.5897
SIQE	0.8318	0.8380

Table: Median correlation across 1000 iterations

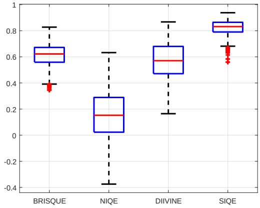


Figure: Box plot of SROCC distributions over 1000 trials

Significance of each conceptual feature

- Each conceptual feature - tested in isolation
- Features only from stitched image - drop in performance, importance of constituent images
  - NR setting - higher performance than NR-IQA methods

Feature	SROCC	LCC
Marginal statistics model (f_{1-12})	0.7951	0.7934
Bivariate model (f_{13-36})	0.6825	0.6972
Features from stitched image (f^s_{1-36}) (when constituent image features are omitted)	0.6524	0.6816
SIQE (f^s_{1-36} and f^c_{1-36})	0.8318	0.8380

Comparison with FR-QA Algorithms

- FR metric - [WeiXu2010] and [Qureshi2012]
- Dependent on Pointwise correspondences
- Performance evaluation - 238 images, images obtained from commercial stitching algorithms ignored

Feature	SROCC	LCC
Xu (PSNR)	0.1795	0.2341
Xu (SSIM)	0.3383	0.4077
Qureshi	0.3238	0.3627
SIQE	0.7848	0.8032

Analysis of Color Distorted Images

- Scores for images with color distortion - close to images with little or no distortion
- Color distortion - less annoying when viewed on a HMD?
- HMD - 90° field of view, instances of non-appearance of color distortion

(a) $MOS = 61.7624$

(b) $MOS = 61.6771$

(c) $MOS = 59.7492$

(d) $MOS = 59.954$

Outline of the Talk

Conclusion

- Subjective quality assessment
  - Stitched image quality database
  - Distortions - ghosting, blur, geometric and color
  - Subjective evaluation on VR
- Objective quality assessment
  - Independent of underlying stitching algorithm
  - Captures stitching induced distortions
  - High correlation with human judgments, outperforms existing quality measures
- Path ahead
  - Model - color distortion characterization
  - Methods to account for geometric shape changes and their relevance in stitched image QA

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Thank You!