USC Viterbi School of Engineering

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Adaptive filtering for video coding with focus change

PoLin Lai[a,b], Yeping Su[*], Peng Yin[a], Cristina Gomila[a], and Antonio Ortega[b]

[a]Thomson Corporate Research, Princeton, NJ
[b]Signal and Image Processing Institute, USC, Los Angeles, CA
[*]The work was developed when this author was with Thomson

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Presentation outline

- **Introduction**
  - Non-translational transformation: Focus change
  - Localized blurriness/sharpness change
- **Review: Reference frame filtering**
  - Predefined filter set
  - Adaptive interpolation filters
- **Proposed approach**
  - Adaptive design based on types of estimated focus changes
- **Simulation Results**
- **Summary**

Introduction

- **Advances in video coding achieve high efficiency**
  - Variable block size
  - Multiple references
  - Quarter pixel interpolation
- **Obtaining good predictors for translational motion**
- **Other types of transformation - linear filtering**
  - Panning, focus, motion blur
- **Focus change (isotropic filtering)**
  - Emphasize different portions of video frames
  - Create special effect for transition during scene changes

Introduction: Focus change

- **An example of focus change over time**
  - http://graphics.stanford.edu/papers/lfcamera/ (© Ren Ng)

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Compensating focus change

- **Generate better reference with linear filtering**
- ***Local* compensation**
  - Different portions may undergo different focus changes
- ***Adaptive* to the mismatches**
  - Different types of focus changes from frame to frame
- **Selection of compensation based on *rate-distortion* (RD)**

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Review: Reference frame filtering

- **Fixed set of blurring filters (M. Budagavi: ICIP 2005)**
  - Camera panning
  - Sharpening filters not considered
  - Predefined set not adaptive to frame difference
- **Adaptive interpolation filters for sub-pixel reference**

  T. Wedi (ICIP 2002, IEEE Trans. CSVT 2003 2006)
  Y. Vatis et al. (ICIP 2005, VCIP 2005, ICIP 2006) *Multiple adaptive* filters
  - Specifically designed to generate sub-pel reference
  - Filters are estimated based on the ***difference between*** Ref. and Cur. frame

Review: Adaptive interpolation filtering

- **Y. Vatis, B. Edler, D. T. Nguyen, I. Wassermann, and J. Ostermann (ICIP 2005, VCIP 2005, ICIP 2006), AIF**

1. Initial motion estimation (with H.264/AVC 6-tap filters for sub-pixels)
2. Divide frames based on subpel portion (SP) of the motion vectors
   For example: (1½, 23¾) and (45½, 6¾) will be assigned the same filter
3. One filter for each location: MMSE estimation

$$e^{SP\ 2} = \sum_{x,y}\left(S_{x,y} - \sum_{i,j=1}^{6} h_{i-1,j-1}^{SP} P_{\tilde{x}+i,\tilde{y}+j}\right)^2$$

4. Generate sub-pixel reference using these filters
5. Final motion compensation
   Test different filters by searching over sub-pixel positions

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Adaptive reference filtering (ARF)

- **Identify different types of focus changes**
  - Estimate MB-wise local focus changes
  - Classify MBs into classes with 'similar' type of focus change
  - Each class is associated with one adaptive filter to be designed
- **Design adaptive filters**
  - For each class:

$$\min_{\psi} \sum_{(x,y)\in C_k} \left(S_{x,y} - \sum_{j=-n}^{n} \sum_{i=-m}^{m} \psi_{ij} R_{x+mv_x+i, y+mv_y+j} \right)^2$$

- **Generate *new references* with these adaptive filters**
- **Final predictive encoding**

ARF: Identify types of focus change

- **One MMSE filter for each macroblock → huge overhead**
- **Partition a frame into regions based on the *type* of focus change**

***Depth*-dependent adaptive filtering: (PoLin Lai et al. VCIP 2007)**

- Multi-view video, cross-view prediction → disparity vector
- Based on disparity, partition frame into regions with different depth levels
- Design filters for each region to minimize residue energy

ARF: Identify types of focus change

- **One MMSE filter for each macroblock → huge overhead**
- **Partition a frame into regions based on the *type* of focus change**

Temporal prediction: No depth information → Estimate local focus changes

ARF: Identify types of focus change

- **One MMSE filter for each macroblock → huge overhead**
- **Partition a frame into regions based on the *type* of focus change**

1. Initial motion search to obtain block correspondence via (mv_x,mv_y)
2. For each MB, calculate MMSE ***parametric*** f_{MB} such that:

$$\min_{f_{mb}} \sum_{(x,y)\in MB} \left(S_{x,y} - f_{mb} * R_{x+mv_x, y+mv_y} \right)^2$$

where the f_{mb} is in the form of $\begin{pmatrix} a & b & a \\ b & c & b \\ a & b & a \end{pmatrix}$

3. Classify MBs into groups

Parameters (a, b, c) as classification inputs

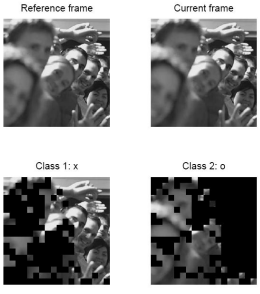
- Roughly capture localized focus change
- Symmetric: Blurring / sharpening modeled as isotropic
- 3 coefficients: Make the classification stable

ARF: Identify types of focus change

- **Intra-coded MBs not involved**
- **(a,b,c) as input features for classification** (4a+4b+c ~ 1)
- **EM classification based on Gaussian Mixture Model (GMM)**
  - GMM: Consider *directional variation* (K-mean: Euclidean distance)
  - Unsupervised classification tool ***(C. Bouman, Purdue University)***
  - Specify the maximum number of Gaussian components: K
  - For k = K, K-1, …., 1: EM classification, estimate GMM with k components
  - Select model with lowest minimum description length (MDL)

ARF: Identify types of focus change

- **Example of microblock classification result**
  - Class 1: Rear people, enhanced; Class 2: Front people, blurred



Original picture: http://graphics.stanford.edu/papers/lfcamera/ (© Ren Ng)

ARF: Design adaptive filters

- **Filter coefficients for each class:**

$$\min_{\psi} \sum_{(x,y)\in C_k} \left(S_{x,y} - \sum_{j=-n}^{n} \sum_{i=-m}^{m} \psi_{ij} R_{x+mv_x+i,y+mv_y+j} \right)^2$$

  - More coefficients: Better compensation, larger overhead

ARF: Design adaptive filters

- **Filter coefficients for each class:**

$$\min_{\psi} \sum_{(x,y)\in C_k} \left(S_{x,y} - \sum_{j=-n}^{n} \sum_{i=-m}^{m} \psi_{ij} R_{x+mv_x+i,y+mv_y+j} \right)^2$$

- **Size: m=n=2 (Comparable to 6x6 interpolation filters)**
  Symmetric properties: *Isotropic* focus changes

$$\psi = \begin{pmatrix} a & b & c & b & a \\ d & e & f & e & d \\ g & h & j & h & g \\ d & e & f & e & d \\ a & b & c & b & a \end{pmatrix}$$ **(9 coefficients)**

ARF: Design adaptive filters

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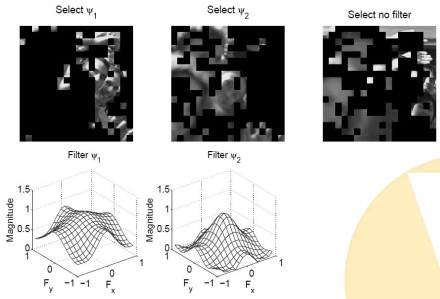
- **Unfiltered reference and multiple filtered references ψ*R, each can also be interpolated for sub-pixel compensation**

ARF: Design adaptive filters



Plain regions, non-effected regions → Select non-filtered

Original picture: http://graphics.stanford.edu/papers/lfcamera/ (© Ren Ng)

ARF: Encoding and signaling

- **Filter coefficients**
  - Quantized and encoded as frame-level overhead
  (Y. Vatis, B. Edler, I. Wassermann, D.T. Nguyen, and J. Ostermann, "*Coding of coefficients of two-dimensional non-separable adaptive Wiener interpolation filter*,"VCIP 2005)

- **Filter selection :**
  - Filtered references by adaptive filters
  - Utilize multiple-reference routine as H.264/AVC
  - The selection is signaled by 'ref_idx'
  - ***Rate-distortion*** based filter selection!

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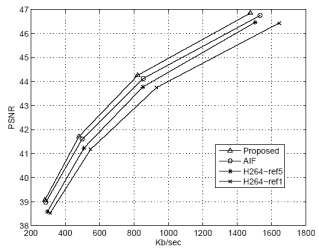
Simulations results

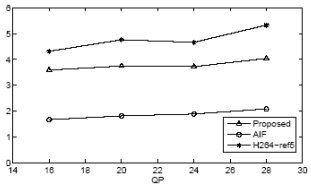
- **H.264/AVC, JM10.2, IPPP configuration**
- **Observed mostly 2~3 filters generated (Total 3~4 references)**
  → Compare with H.264 multiple reference method

"fondue-multi.wmv", by Yi-Ren Ng, Light Field Photography project, Stanford Computer Graphics Lab. http://graphics.stanford.edu/papers/lfcamera/refocus/ (We encoded frame 126-170)



Simulation results (2)

"ME time ratio" as compared to H.264 with 1 reference
- Profiling tool with JM 10.2, full search for all references



Reuse motion info:
- Initial MV as predictor for the final encoding
  (Submitted to CSVT special issue for multi-view video coding)

Summary

- **Focus change**
  - Transformation not covered by translational motion
  - Localized blurriness/sharpness mismatches
- **Proposed Adaptive reference filtering**
  - Use ***block-wise parametric filters*** to estimate localized focus changes
  - Classify image into regions with different types of focus change (EM algorithm for GMM)
  - Multiple adaptive filters for reference frame
- **For sequence with severe localized focus changes, simulation results outperform H.264/AVC and other adaptive filtering approaches**

Questions?