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Fuzzy contrast enhancement for images in the compressed domain

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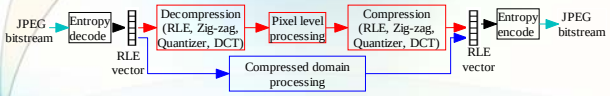
Brief Overview

- Compressed domain image processing algorithms – in encoded JPEG image domain
  - Provide a powerful computation alternative to classical
- This field is in its beginning
  - The algorithms reported in the literature are mostly based on linear arithmetic point operations (addition, substraction, multiplication)
- Addressed problem
  - Implementing a nonlinear operator using compressed domain processing – digital image enhancement using fuzzy theory
- Advantage:
  - No need to decompress/ recompress the whole image prior to enhance/ after enhance
  - For the 8×8 size blocks processed in the compressed domain, the enhancement algorithm implies a single comparison of the DC coefficient with the threshold (instead of 64 - at pixel level)

JPEG domain image enhancement



- **There are two ways to enhance the images compressed with JPEG**
  - **Compressed domain processing = no decompression**
  - **Pixel level processing = enhance the image after decompression**
- **In our algorithm the enhancement unit is added to the JPEG decoder just before the decompression**
  - **Adaptive minimal decompression:**
    - **full decompression no longer needed, but**
    - **decompression used for blocks with many details for improved accuracy**

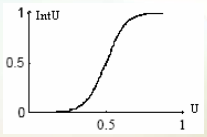
Contrast improvement with fuzzy theory

Analytical and graphical representation of the fuzzy contrast enhanced function:

$$U=\{u(i,j)\in[0,1],\ where\ i=0,\ 1,...,\ H-1,\ j=0,\ 1,...,\ W-1\}$$

$$IntU(i,j)=\begin{cases}2\cdot[u(i,j)]^2,\ if\ \ 0\le u(i,j)\le 0.5\\ 1-2\cdot[1-u(i,j)]^2,\ if\ \ 0.5\le u(i,j)\le 1\end{cases}$$

$$where\ \ i=0,1,...,H\text{-}1;\ \ j=0,1,...,W\text{-}1$$



- ***U* is original image and *IntU* is enhanced image**
- **For contrast enhancement with fuzzy functions - the square of each pixels' luminance is needed => a nonlinear operation**

Convolution of the image in the compressed domain

- the square of each pixels' luminance is needed – nonlinear operation; implemented in the compressed domain using convolution:

$$U_{dct,sq}(x_1,x_2)=\frac{1}{4\cdot Q(x_1,x_2)}\sum_i\sum_j C(i,x_1)\cdot C(j,x_2)\cdot u(i,j)\cdot u(i,j)=$$

$$=\sum_{y_1,y_2,w_1,w_2} U_{dct}(y_1,y_2)\cdot U_{dct}(w_1,w_2)\cdot W_Q(y_1,y_2,w_1,w_2,x_1,x_2)$$

$$where:\ \ W_Q(y_1,y_2,w_1,w_2,x_1,x_2)=\frac{Q(y_1,y_2)\cdot Q(w_1,w_2)}{256\cdot 64\cdot Q(x_1,x_2)}W(x_1,y_1,w_1)\cdot W(x_2,y_2,w_2)$$

$$with:\ \ W(x,y,w)=\sum_i C(i,x)\cdot C(i,y)\cdot C(i,w)$$

$$C(i,x)=A(x)\cos\frac{(2\cdot i+1)\cdot x\cdot\pi}{16};\quad A(x)=\begin{cases}\frac{1}{\sqrt{2}},\ for\ x=0\\ 1,\ for\ x\ne 0\end{cases}$$

$U_{dct}(i,j)$ – DCT coefficients in the block
$U_{dct,sq}(i,j)$ – DCT of the block matrix
$U_{sq}(i,j)=u^2(i,j)$

- **U_{dct} – is zero for most values**
- **In the $W_Q(y_1,y_2,w_1,w_2,x_1,x_2)$ function only about 4% of the terms are non-zero => we can efficiently compute this sum**

Fuzzy image enhancement in the compressed domain

$$IntU_{dct}=\begin{cases}U_{dct,sq}+2\cdot U_{dct}-128,\ if\ \ DC\le 0\\ 2\cdot U_{dct}-U_{dct,sq}-128,\ if\ \ DC>0\end{cases}$$

$IntU_{dct}$ = the enhanced 8x8 image block in the compressed domain

- **Is based on the contrast improvement method with fuzzy theory**
- **The luminance values are scaled symmetrically towards 0 => the threshold for the fuzzy algorithm in the compressed domain should have the value 0**
- **The algorithm is applied on the DCT coefficients - only the DC coefficient will be compared with the threshold for each 8x8 block**

Image enhancement algorithm

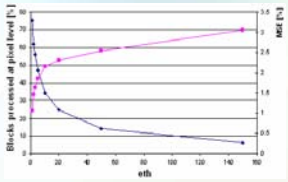
- for each 8×8 pixels block of the JPEG image
  - The average amount of A.C. energy E_{AC} is computed

$$E_{AC} = \frac{\sum_{i,j} \left| U_{dct,A.C.}(i,j) \right|^2}{63}$$

  - If $E_{AC} < e_{th}$ - then the block can be considered to have quasi-uniform luminance and it will be processed in the compressed domain
  - If $E_{AC} > e_{th}$ - then the block has a significant content of details and it will be decompressed, every pixel from the block being processed separately (point-wise).

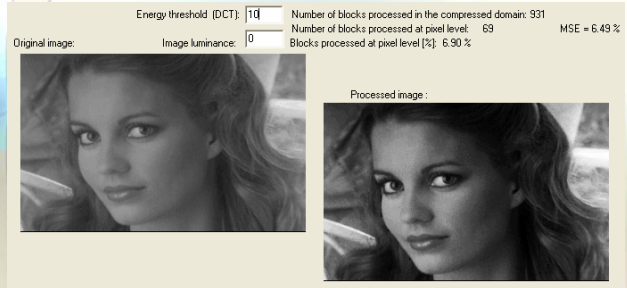
Note: the value e_{th} represents the selection threshold between the quasi-uniform blocks and the blocks with a significant number of details

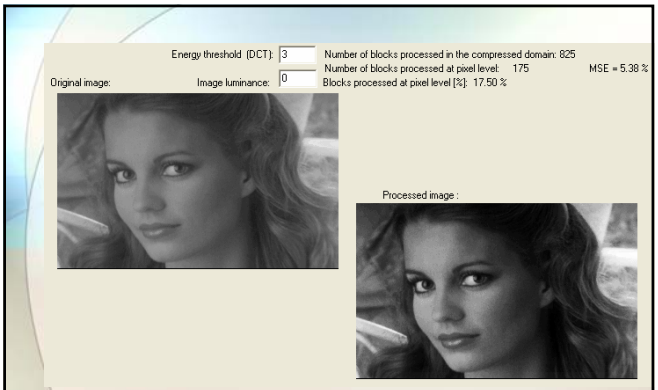
The e_{th} threshold selection

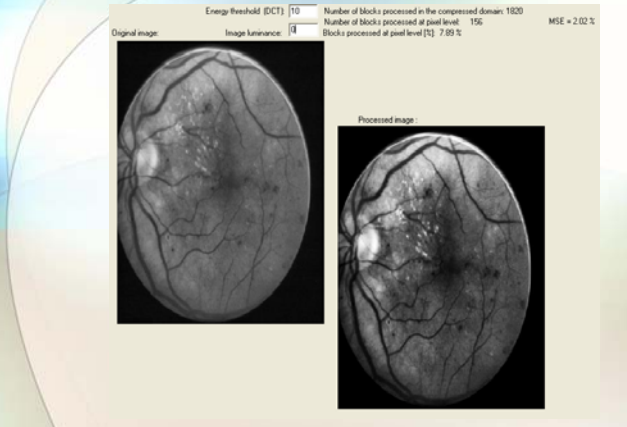


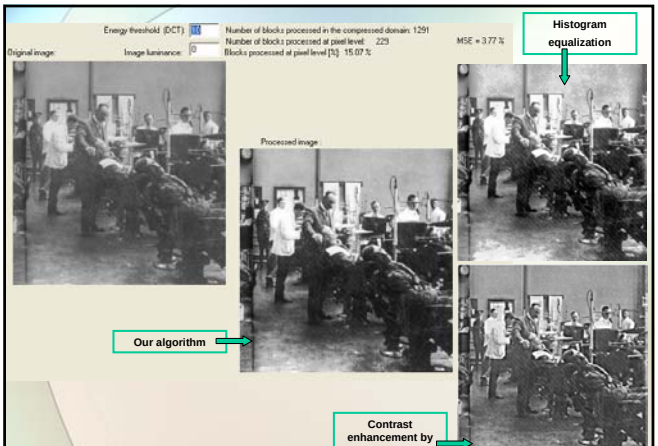
- The value e_{th} is chosen from the experiments, taking into account the image statistics
- A very small e_{th} value will always lead to very good quality of the output images,
  - but the number of processed blocks in the compressed domain will be quite small,
  - so the complexity of the computing algorithm is not significantly small compared with the direct processing on the pixel level
- An appropriate value will lead to the increase of the number of blocks processed in the compressed domain
  - => in this way we can obtain a fast fuzzy algorithm for image enhancement

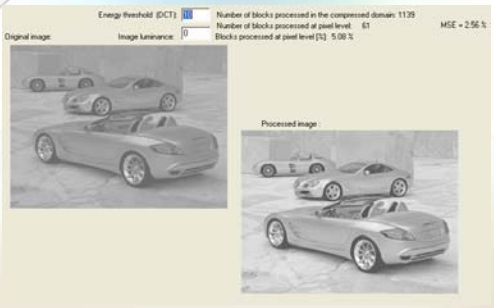
Experimental results

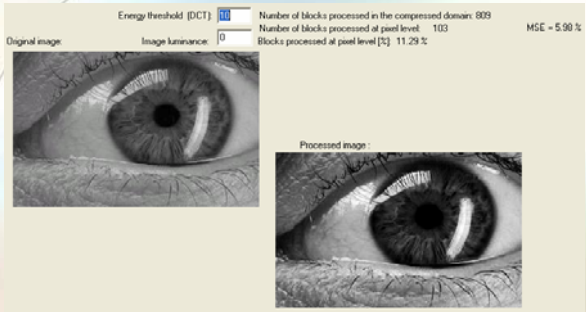












Conclusion

- **The experimental performance results show that:**
  - **the computational complexity of the enhancement can be significantly reduced:**
    - **at most 25% blocks (for complex images) are processed at pixel level**
  - **preserving the qualitative performance of classical algorithm**

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