

Восстановление сжатого ВИДЕО

Моисейцев Алексей

*Video Group
CS MSU Graphics & Media Lab*

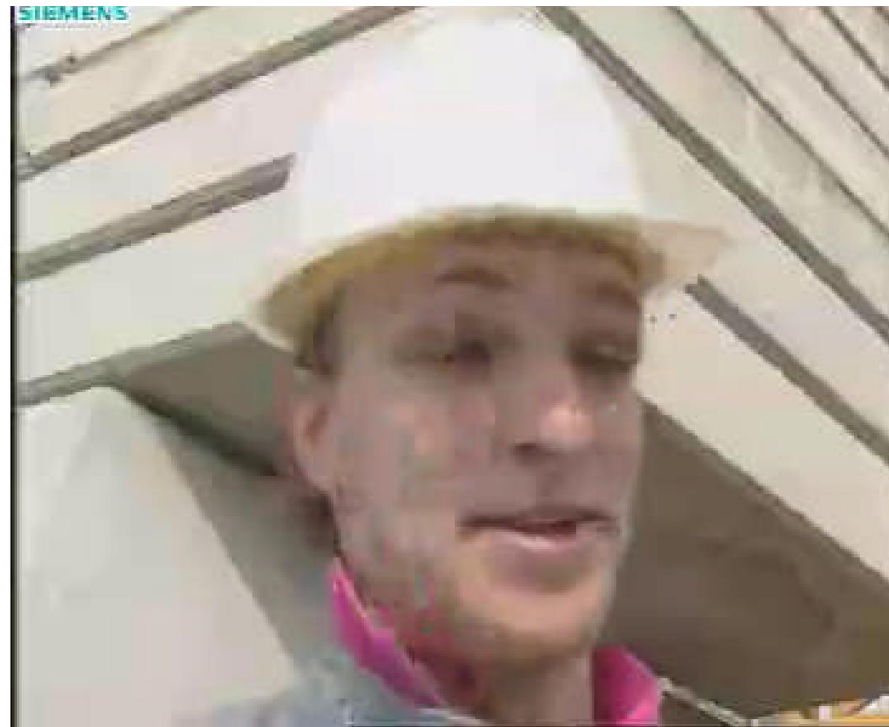


Содержание

- **Введение**
- **Простые модели**
 - Adaptive Fuzzy Post-Filtering
 - DCT Re-application
- **Классификация**
 - Support Vector Regression
 - Modified Mean-Removed Classified Vector Quantization
- **Регуляризация**
- **Заключение**

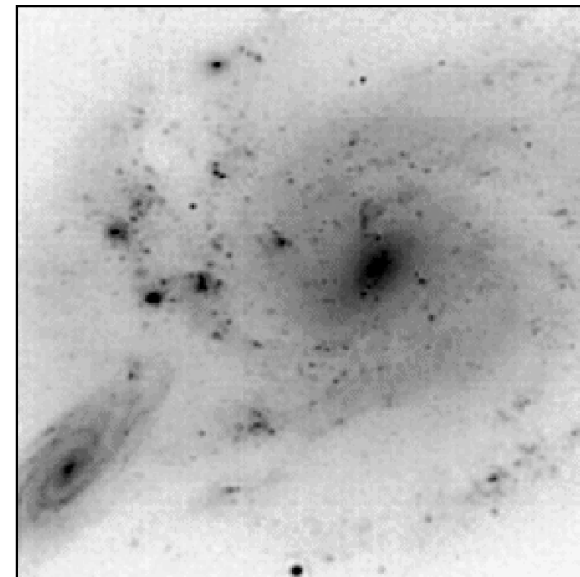


Введение





Введение





Содержание

- Введение
- Простые модели
 - **Adaptive Fuzzy Post-Filtering**
 - DCT Re-application
- Классификация
 - Support Vector Regression
 - Modified Mean-Removed Classified Vector Quantization
- Регуляризация
- Заключение

Adaptive Fuzzy Post-Filtering

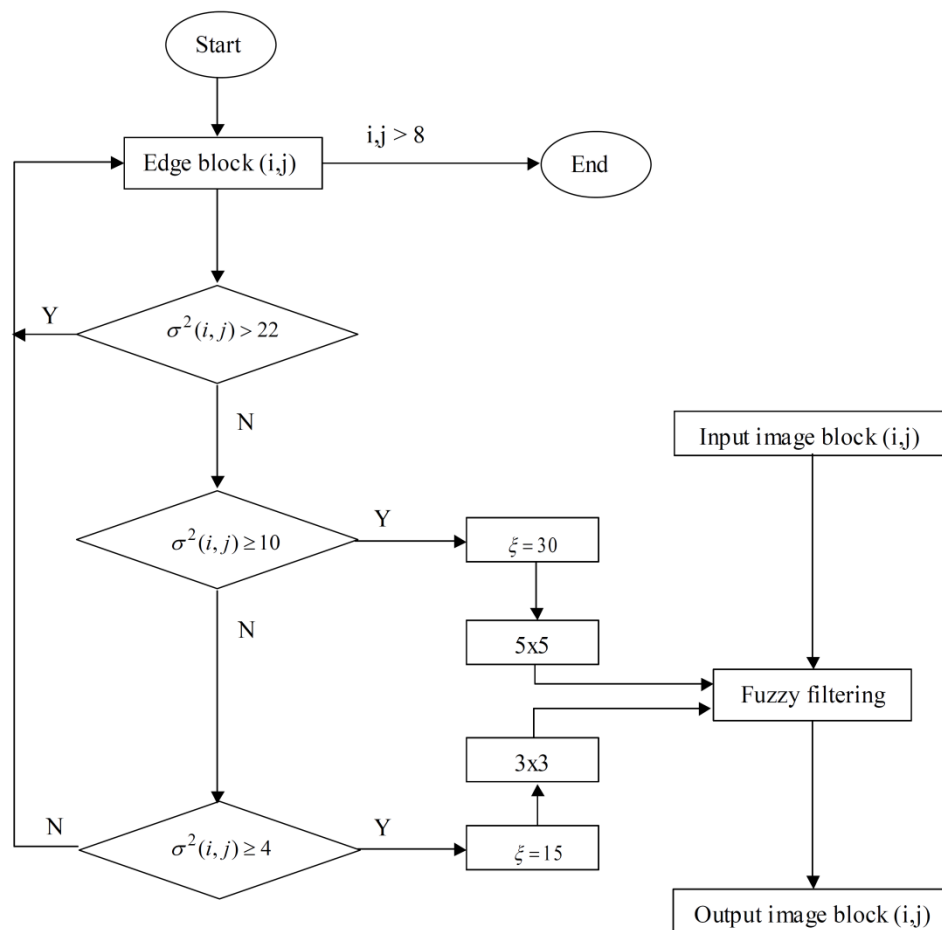
$$\tilde{X}_c = \frac{\sum_{j=1}^N X_j \mu(X_c, X_j)}{\sum_{j=1}^N \mu(X_c, X_j)}$$

$$\mu(a, b) = e^{-(a-b)^2 / 2\xi^2}$$

ξ^2 – сила фильтра,

зависит от типа блока

\tilde{X}_c – новое значение пикселя



Adaptive Fuzzy Post-Filtering



Adaptive Fuzzy Post-Filtering



PSNR 30.61 dB



PSNR 30.93 dB

Adaptive Fuzzy Post-Filtering for Highly Compressed Video. Hao-Song Kong, Yao Nie, Anthony Vetro, Huifang Sun, Kenneth E. Barner. ICIP 2004.



Adaptive Fuzzy Post-Filtering

- Преимущества
 - Быстрая работа
 - Простота в реализации
- Недостатки
 - Просто маскировка артефактов
 - Замыливание изображения



Содержание

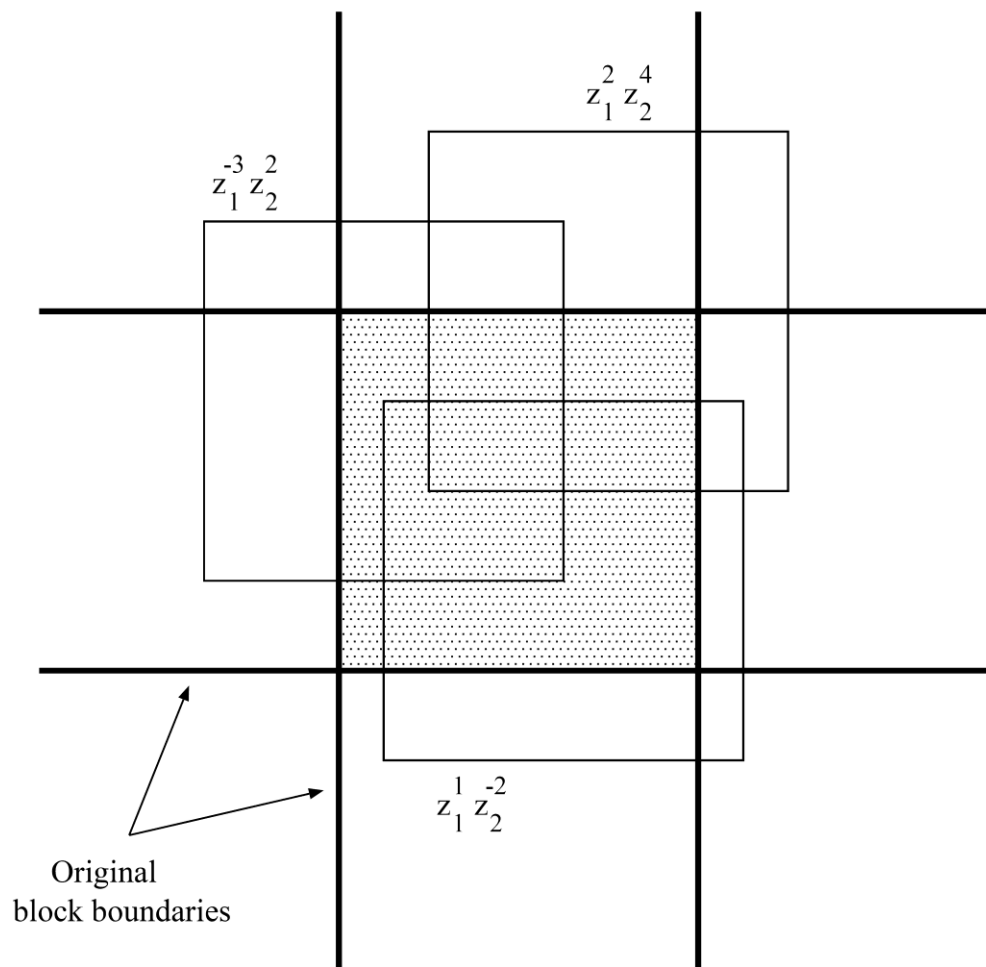
- Введение
- Простые модели
 - Adaptive Fuzzy Post-Filtering
 - **DCT Re-application**
- Классификация
 - Support Vector Regression
 - Modified Mean-Removed Classified Vector Quantization
- Регуляризация
- Заключение



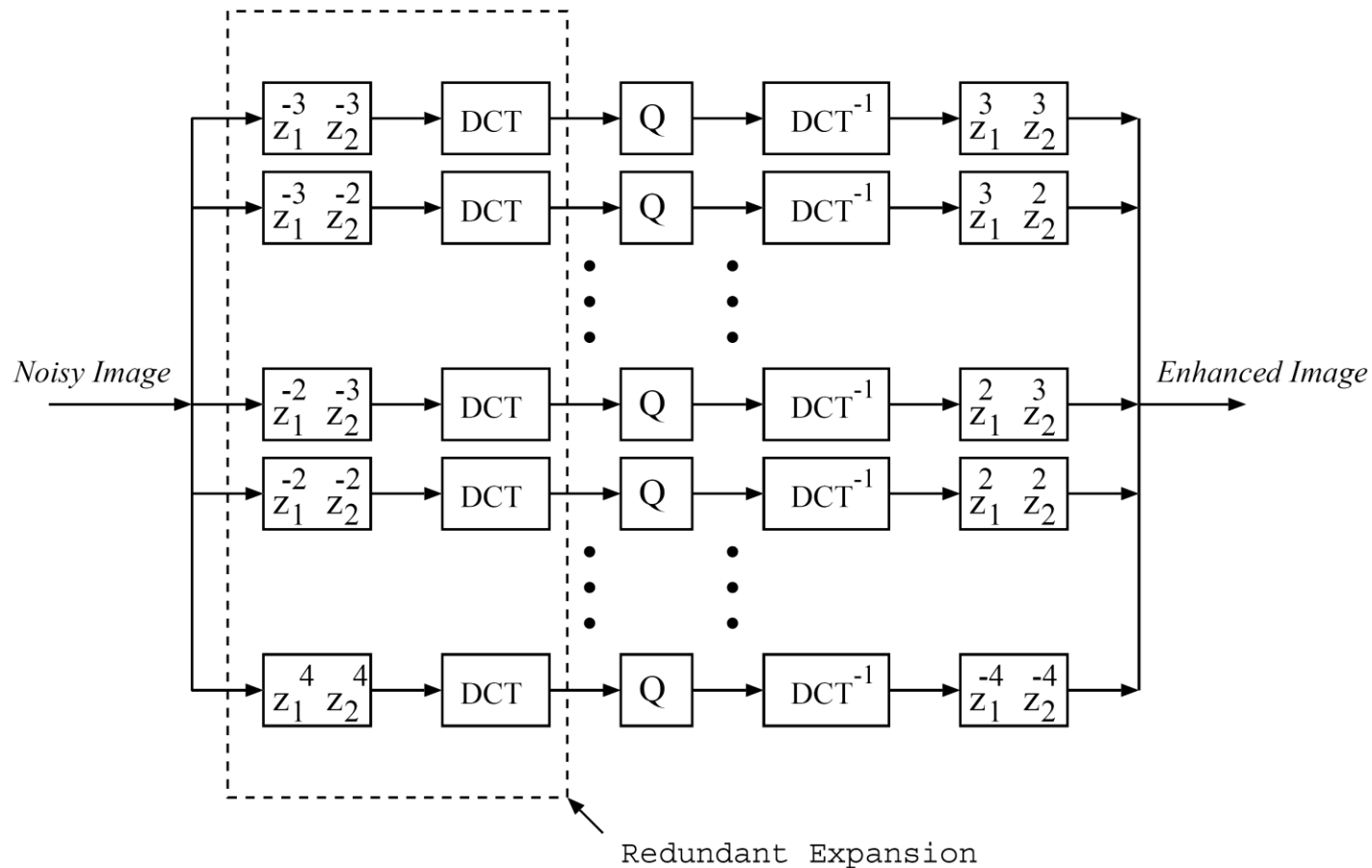
DCT Re-application

1. Сдвинуть изображение по вертикали и горизонтали на (i,j)
2. Сжать изображение
3. Вернуть изображение обратно, т.е. сдвинуть на $(-i,-j)$
4. Повторить для всех сдвигов из $[-3, 4] \times [-3, 4]$
5. Усреднить результат

DCT Re-application



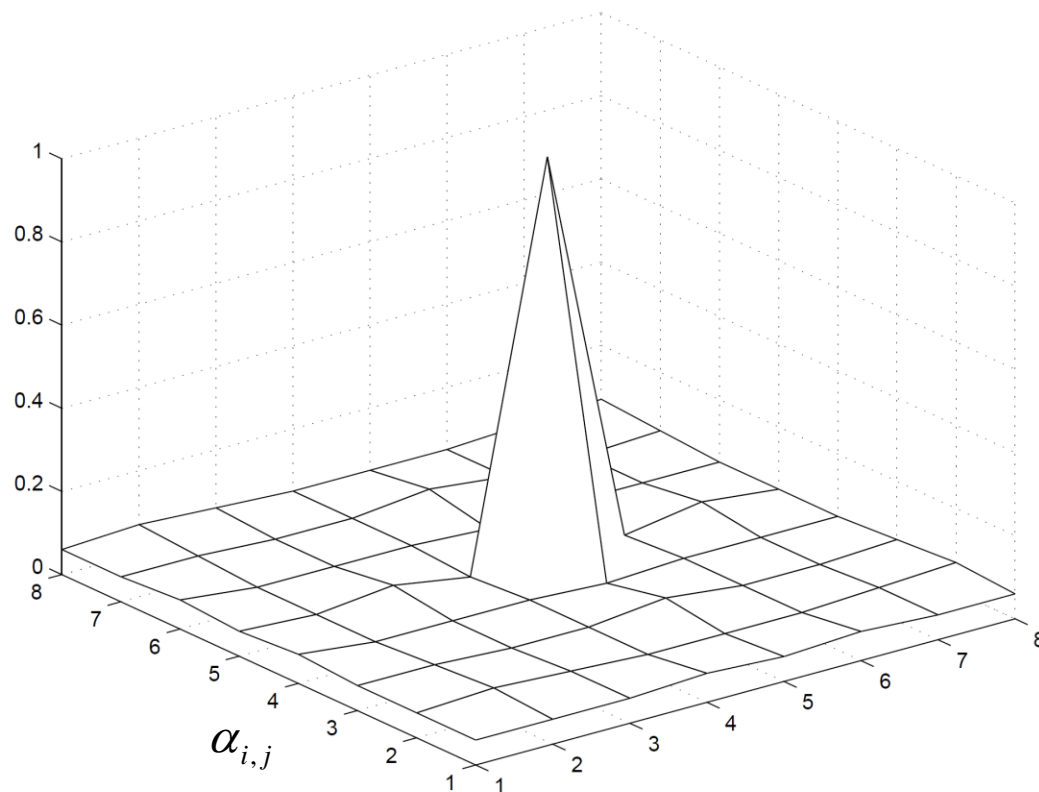
DCT Re-application



DCT Re-application

$$y = \sum_{i,j} \alpha_{i,j} D^{(-i,-j)} Q(D^{(i,j)} x)$$

- x - сжатое изображение
- y - восстановленное изображение
- D - оператор сдвига
- Q - оператор кодирования и декодирования



DCT Re-application

Пример работы

 Q_1
 Q_2
 Q_3

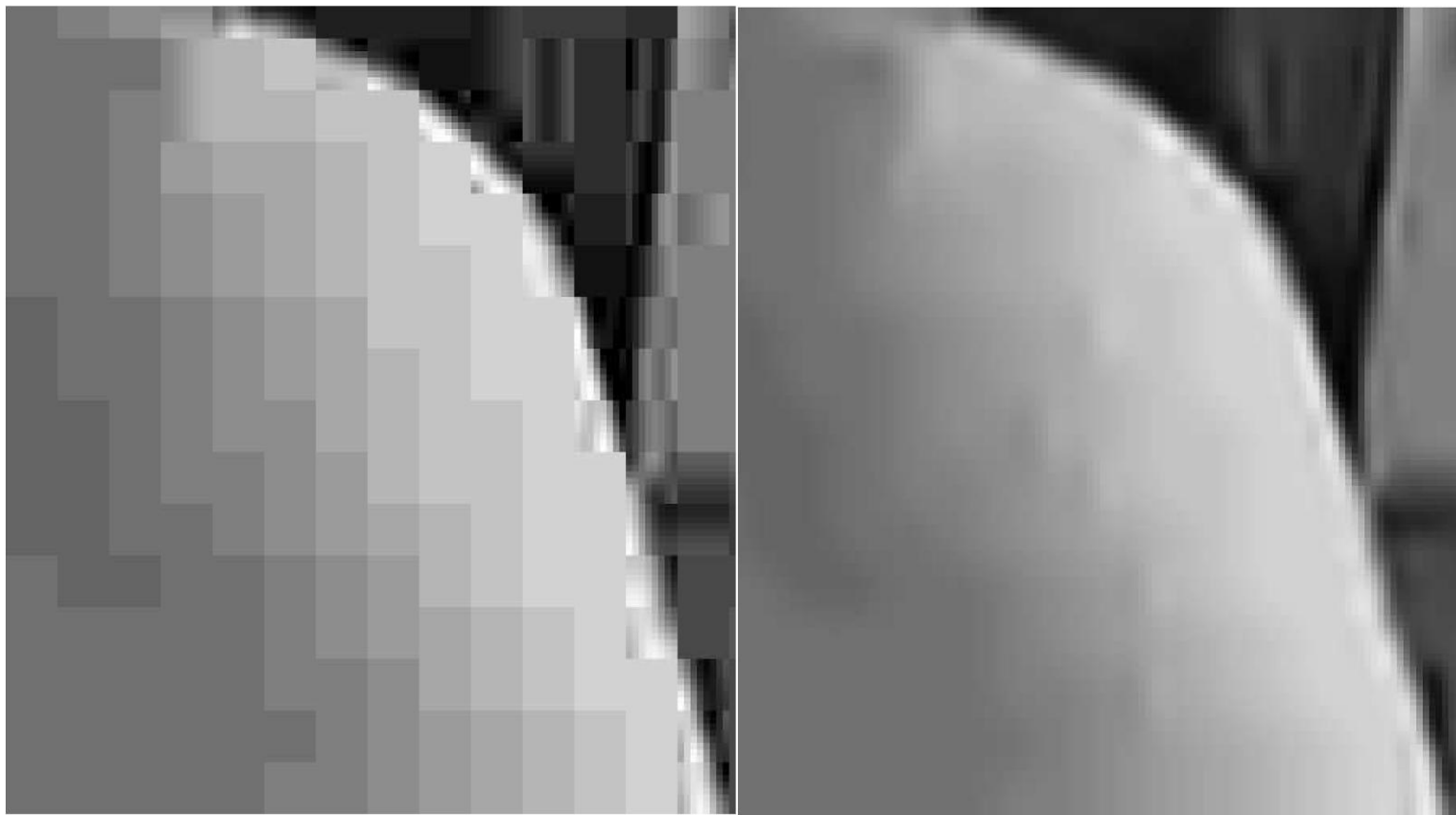
20	24	28	32	36	80	98	144	50	60	70	70	90	120	255	255	110	130	150	192	255	255	255	255
24	24	28	34	52	70	128	184	60	60	70	96	130	255	255	255	130	150	192	255	255	255	255	255
28	28	32	48	74	114	156	190	70	70	80	120	200	255	255	255	150	192	255	255	255	255	255	255
32	34	48	58	112	128	174	196	70	96	120	145	255	255	255	255	192	255	255	255	255	255	255	255
36	52	74	112	136	162	206	224	90	130	200	255	255	255	255	255	255	255	255	255	255	255	255	255
80	70	114	128	162	208	242	200	120	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
98	128	156	174	206	242	240	206	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
144	184	190	196	224	200	206	208	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255

Quantization	Lenna	Mandrill	Stream	Goldhill	Barbara
Q_1	0.66	0.19	0.23	0.52	1.04
Q_2	1.03	0.23	0.42	0.74	0.89
Q_3	1.16	0.40	0.55	0.91	1.04

Enhancement of JPEG-Compressed Images by Re-application of JPEG. Aria Nosratinia. Department of Electrical Engineering, University of Texas at Dallas, Richardson. 2002.

DCT Re-application

Пример работы



Enhancement of JPEG-Compressed Images by Re-application of JPEG. Aria Nosratinia. Department of Electrical Engineering, University of Texas at Dallas, Richardson. 2002.

DCT Re-application

Пример работы



Enhancement of JPEG-Compressed Images by Re-application of JPEG. Aria Nosratinia. Department of Electrical Engineering, University of Texas at Dallas, Richardson. 2002.



DCT Re-application

- **Преимущества**

- Заметное уменьшение артефактов
- Прост в реализации

- **Недостатки**

- Желательно знать параметры сжатия
- Ориентирован на изображения
- Невысокая скорость работы
(~58 умножений на пиксель)

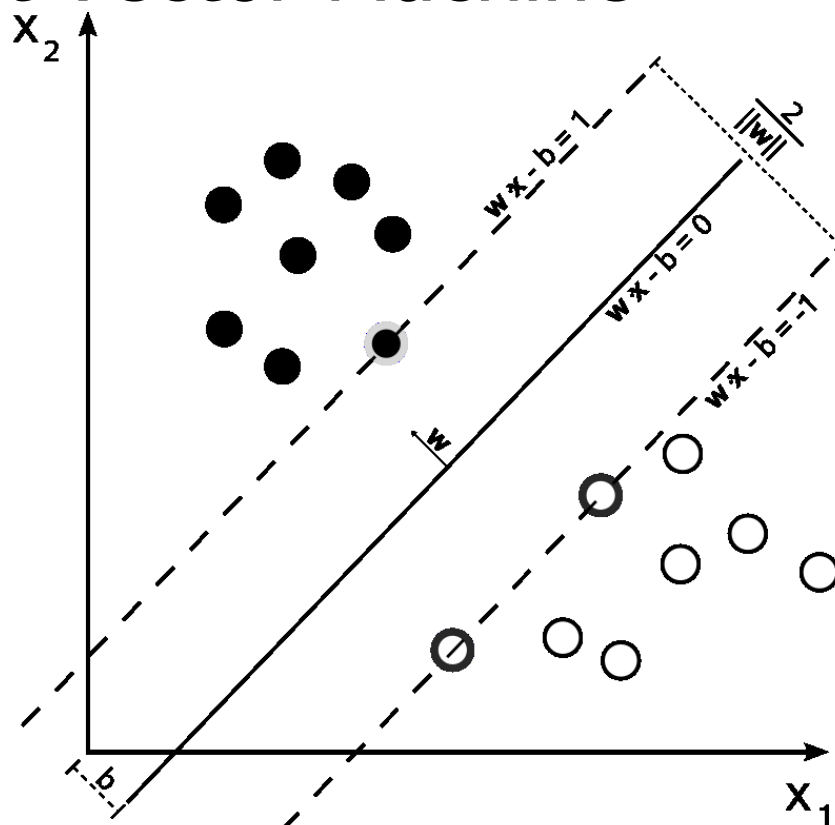


Содержание

- Введение
- Простые модели
 - Adaptive Fuzzy Post-Filtering
 - DCT Re-application
- Классификация
 - **Support Vector Regression**
 - Modified Mean-Removed Classified Vector Quantization
- Регуляризация
- Заключение

Support Vector Regression

- Support Vector Machine



Support Vector Regression

$y = f(x)$ - моделируемая функция

(x_i, y_i) - тренировочные данные

$y = \langle \phi(w), x \rangle + b$ - вид модели

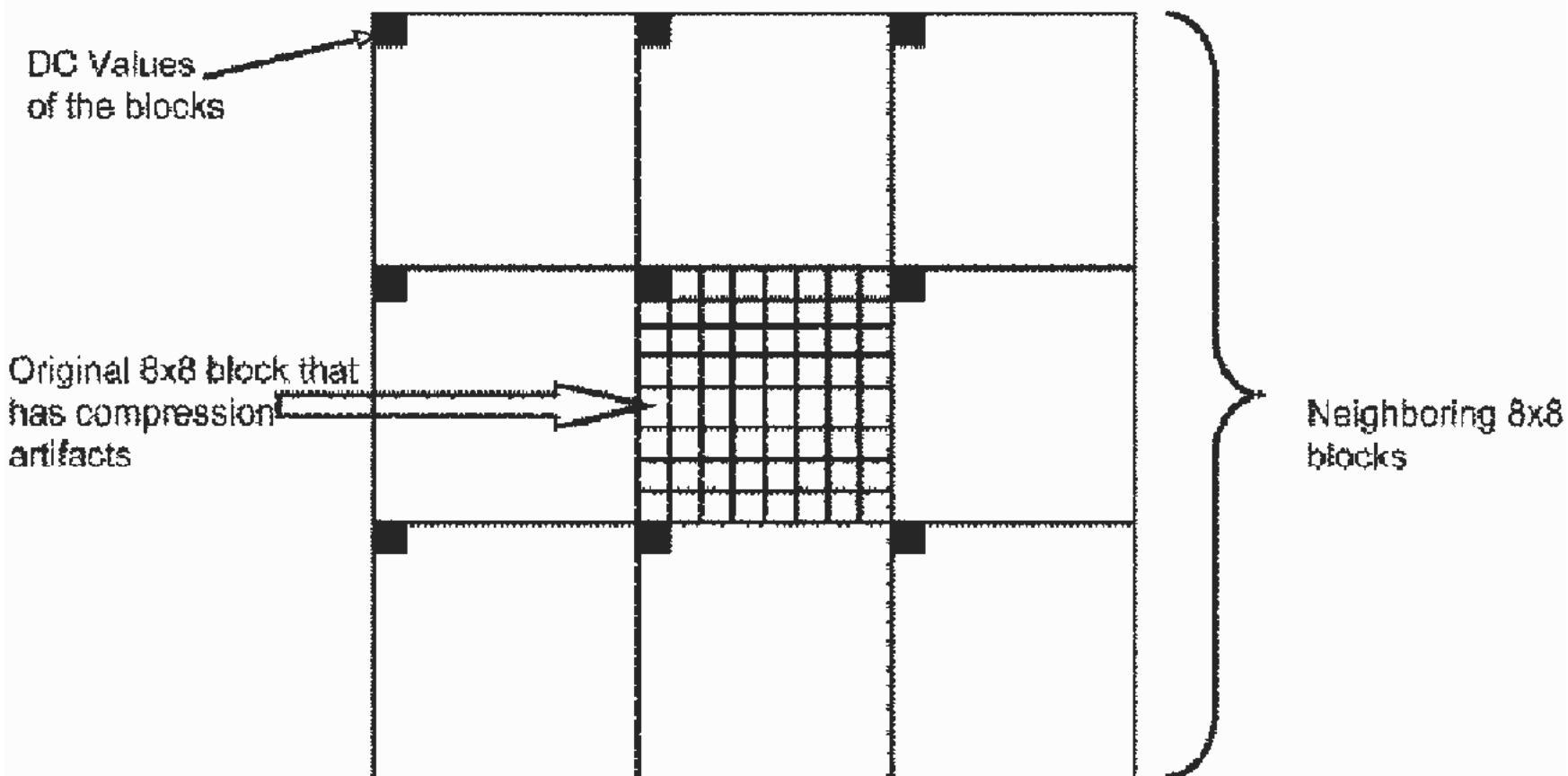
Минимизация

$$\frac{1}{2} \langle w, w \rangle + C \sum_{i=1}^l (\xi_i + \xi_i^*)$$

при условии

$$\begin{cases} y_i - \langle w, \phi(x_i) \rangle - b & \leq \varepsilon + \xi_i & \varepsilon & \text{— допустимое отклонение для всех элементов} \\ \langle w, \phi(x_i) \rangle + b - y_i & \leq \varepsilon + \xi_i^* & \xi_i, \xi_i^* & \text{— отклонение для каждого элемента} \\ \xi_i, \xi_i^* & \geq 0 & & \end{cases}$$

Support Vector Regression





Support Vector Regression





Support Vector Regression





Support Vector Regression

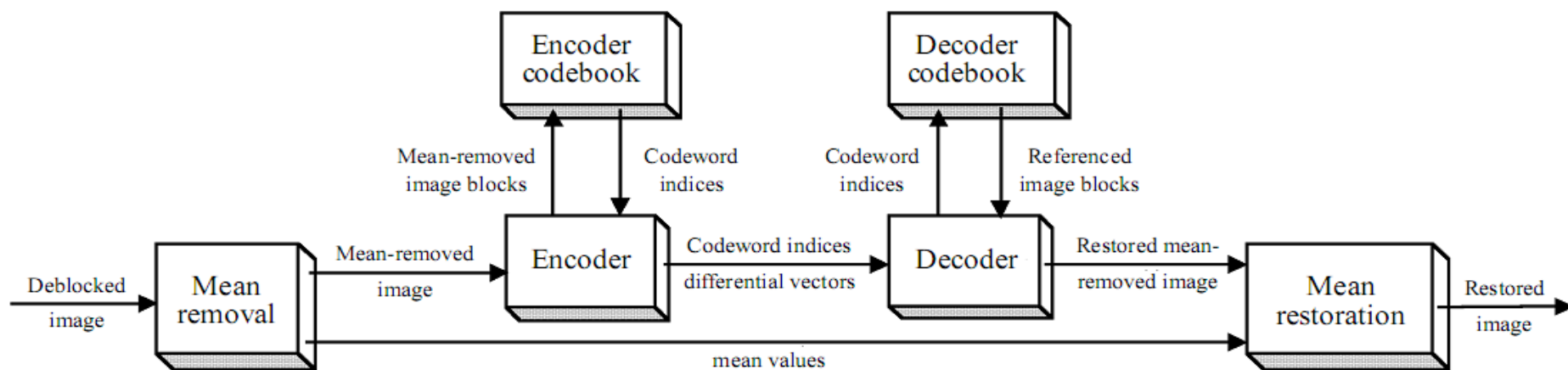
- Преимущества
 - Визуальное улучшение на некоторых типах изображений
- Недостатки
 - Зависимость от обучающей выборки
 - Сложно прогнозируемое поведение



Содержание

- Введение
- Простые модели
 - Adaptive Fuzzy Post-Filtering
 - DCT Re-application
- Классификация
 - Support Vector Regression
 - **Modified Mean-Removed Classified Vector Quantization**
- Регуляризация
- Заключение

MMRCVQ (Modified Mean-Removed Classified Vector Quantization)



Artifact reduction of compressed color images using modified mean-removed classified vector quantization. Jim Zone-Chang Lai, Yi-Ching Liaw, and Winston Lo. *Journal of the Chinese Institute of Engineers*, Vol. 27, No. 5, pp. 747-751 (2004)

MMRCVQ

Построение кодирующих последовательностей



- Выбор блоков 4x4

$T' = \{x'_i : i = 1, \dots, N\}$ – сжатые данные

$T = \{x_i : i = 1, \dots, N\}$ – исходные данные

- Нормировка

$$z'_i = x'_i - \bar{x}'_i, \quad z_i = x_i - \bar{x}_i$$

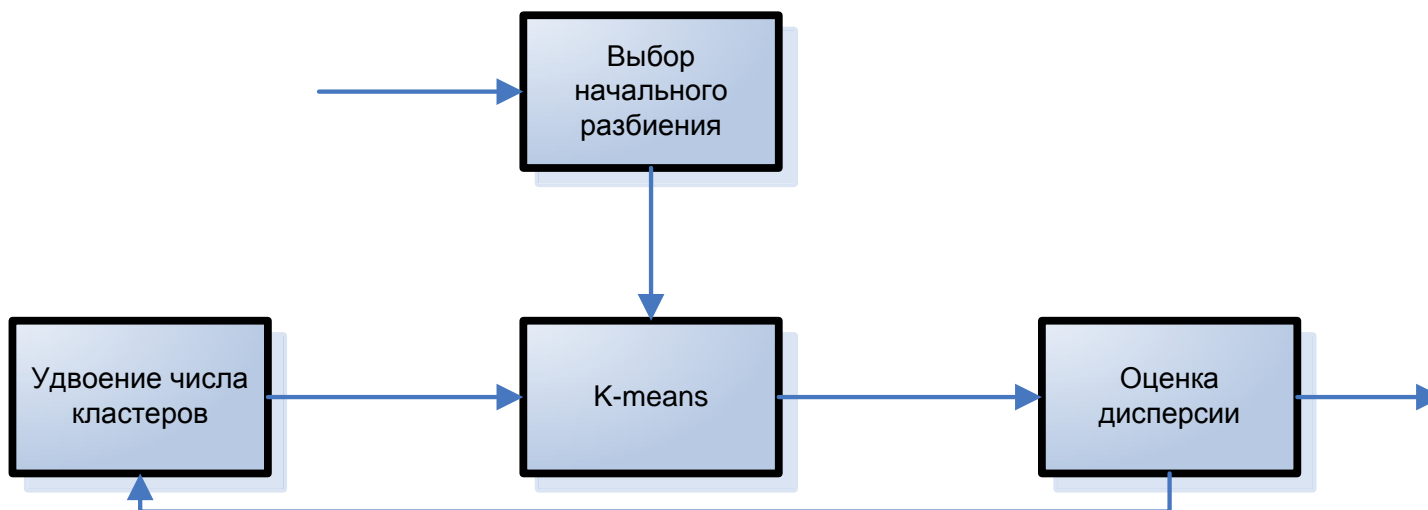
- Кластеризация

Алгоритм Linde-Buzo-Gray

Artifact reduction of compressed color images using modified mean-removed classified vector quantization. Jim Zone-Chang Lai, Yi-Ching Liaw, and Winston Lo. Journal of the Chinese Institute of Engineers, Vol. 27, No. 5, pp. 747-751 (2004)

MMRCVQ

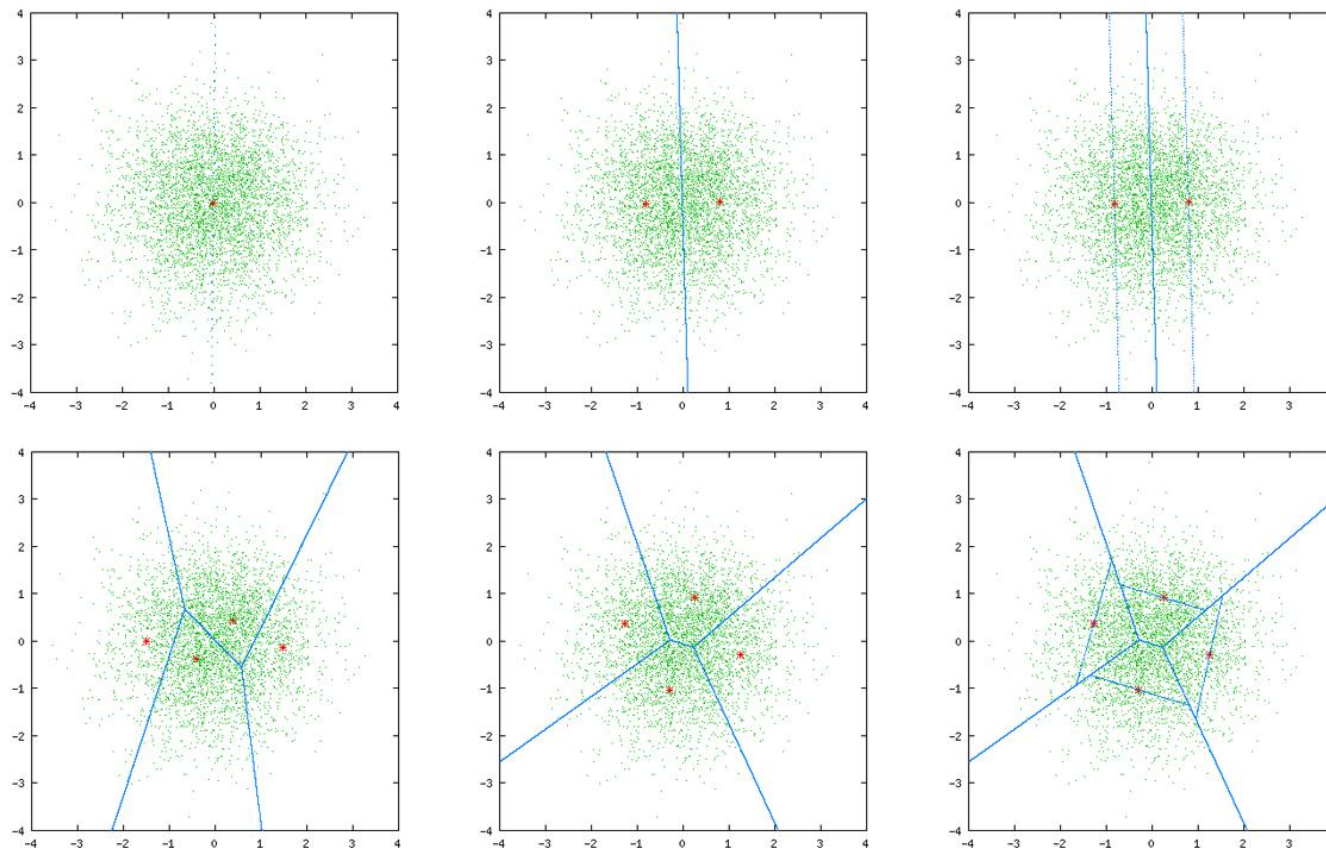
Linde-Buzo-Gray



Artifact reduction of compressed color images using modified mean-removed classified vector quantization. Jim Zone-Chang Lai, Yi-Ching Liaw, and Winston Lo. *Journal of the Chinese Institute of Engineers*, Vol. 27, No. 5, pp. 747-751 (2004)

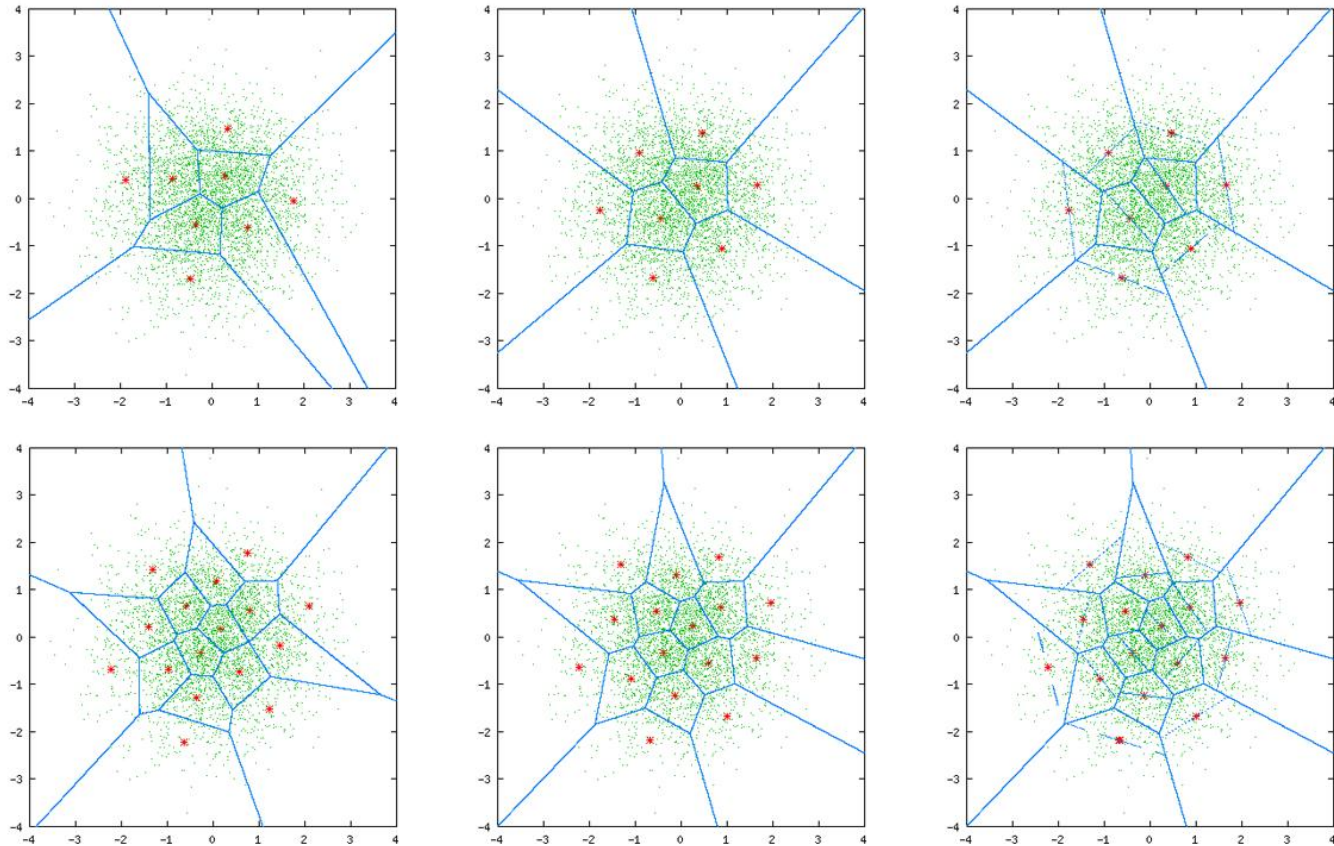
MMRCVQ

Linde-Buzo-Gray



MMRCVQ

Linde-Buzo-Gray



MMRCVQ

- Выбор кодирующих последовательностей

$$C' = \{y'_i : i = 1, \dots, M\}$$

- Разбиение несжатых данных

$$R_k = \{x_i \mid d(x'_i, y_k) \leq d(x'_i, y_l)\} : i \neq l \quad k = 1 \dots M, \quad i = 1 \dots N$$

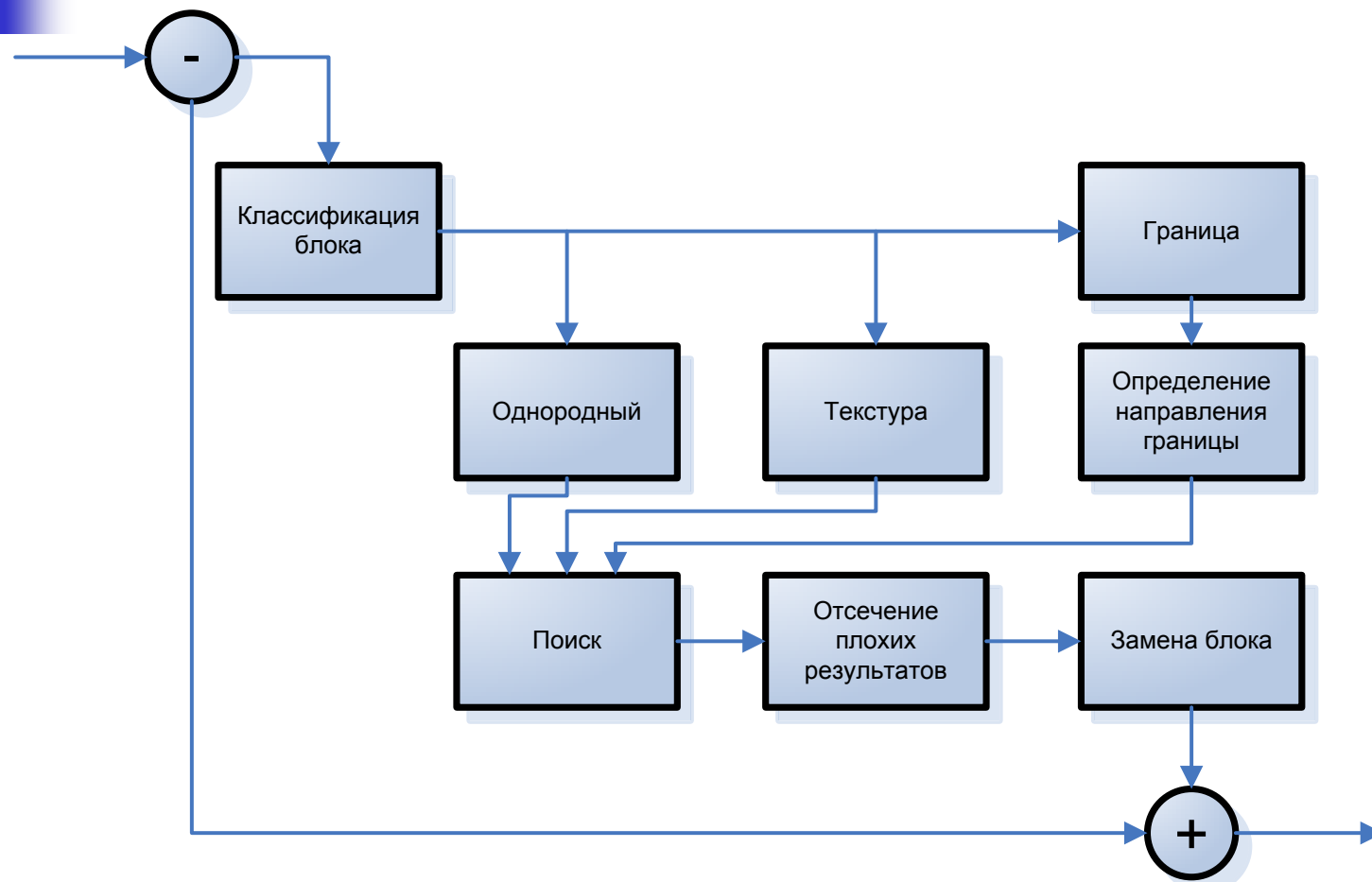
- Выбор декодирующих последовательностей

$$y_i = \frac{\sum_{x_j \in R_i} x_j}{|R_i|}$$

Artifact reduction of compressed color images using modified mean-removed classified vector quantization. Jim Zone-Chang Lai, Yi-Ching Liaw, and Winston Lo. Journal of the Chinese Institute of Engineers, Vol. 27, No. 5, pp. 747-751 (2004)

MMRCVQ

Восстановление



Artifact reduction of compressed color images using modified mean-removed classified vector quantization. Jim Zone-Chang Lai, Yi-Ching Liaw, and Winston Lo. Journal of the Chinese Institute of Engineers, Vol. 27, No. 5, pp. 747-751 (2004)

MMRCVQ

Результаты



Table 1 PSNRs of compressed, deblocked, and reconstructed images

Test image	Compressed image			Deblocked image			Improvement of reconstructed image		
	Y	C_r	C_b	Y	C_r	C_b	Y	C_r	C_b
Space	30.60	40.07	37.89	0.64	0.54	0.47	0.88	0.88	0.70
Bird	29.94	33.71	33.36	0.50	0.39	0.29	0.58	0.52	0.48
Wall	25.80	36.81	37.26	0.27	0.41	0.39	0.48	0.72	0.76
Door	30.48	33.41	35.95	0.37	0.54	0.47	0.50	1.26	0.94
Hat	31.58	36.24	35.41	0.61	0.33	0.36	0.90	0.49	0.58
Woman	30.77	34.45	37.69	0.61	0.61	0.38	0.68	0.99	0.67
Bike	25.18	33.46	34.02	0.47	0.45	0.47	0.75	0.67	0.66
Sailboat 1	26.70	36.66	36.3	0.32	0.39	0.40	0.55	0.64	0.77
Flower	30.26	35.10	34.74	0.76	0.46	0.46	0.92	0.71	0.66
House	24.94	35.51	35.34	0.20	0.46	0.41	0.66	0.71	0.59
Sailboat 2	30.07	35.93	35.96	0.54	0.47	0.42	0.92	0.77	0.60
Airplane	29.71	38.53	36.29	0.45	0.47	0.47	0.92	0.72	0.73
Coast	27.23	36.49	36.09	0.36	0.45	0.48	0.51	0.63	0.71
Parrot	31.93	35.56	35.25	0.75	0.60	0.61	0.87	0.80	0.82
Beach	30.74	36.19	37.83	0.45	0.44	0.37	0.83	0.61	0.56
Raft	26.97	32.91	33.18	0.48	0.29	0.31	0.61	0.34	0.41
Girl	30.16	34.78	36.56	0.49	0.49	0.61	0.64	0.68	0.85
Island	29.56	38.93	36.68	0.46	0.34	0.51	0.56	0.62	0.80
Effigy	28.82	37.51	36.39	0.55	0.42	0.37	0.69	0.75	0.65
Beacon	28.05	36.64	36.83	0.34	0.52	0.45	0.59	0.89	0.67
Lena	31.13	33.83	33.56	0.81	0.35	0.43	0.83	0.47	0.52
Average computing time (second)							0.68	0.6	0.72

Artifact reduction of compressed color images using modified mean-removed classified vector quantization. Jim Zone-Chang Lai, Yi-Ching Liaw, and Winston Lo. Journal of the Chinese Institute of Engineers, Vol. 27, No. 5, pp. 747-751 (2004)

MMRCVQ

Результаты



Artifact reduction of compressed color images using modified mean-removed classified vector quantization. Jim Zone-Chang Lai, Yi-Ching Liaw, and Winston Lo. *Journal of the Chinese Institute of Engineers*, Vol. 27, No. 5, pp. 747-751 (2004)



MMRCVQ

- Преимущества
 - Хорошее качество
 - Приемлемая скорость восстановления
- Недостатки
 - Только устранение блочности



Содержание

- Введение
- Простые модели
 - Adaptive Fuzzy Post-Filtering
 - DCT Re-application
- Классификация
 - Support Vector Regression
 - Modified Mean-Removed Classified Vector Quantization
- **Регуляризация**
- Заключение

Regularized Iterative Restoration

$$f = \begin{bmatrix} f_1 \\ f_2 \\ \vdots \\ f_k \\ \vdots \\ f_N \end{bmatrix}, \quad g = \begin{bmatrix} g_1 \\ g_2 \\ \vdots \\ g_k \\ \vdots \\ g_N \end{bmatrix}, \quad n = \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_k \\ \vdots \\ n_N \end{bmatrix}$$

f – исходный кадр

g – наблюдаемый кадр

n – шум

D – оператор линейной деградации

$$g = Df + n$$

$$J(f) = \|f - g\|^2 + \lambda E(f)$$

Regularized Iterative Restoration

Пространственная регуляризация

$$(Q_{HB}f)(i, j) = \begin{cases} f(i, j) - f(i+1, j) & \text{if } i = 8l \text{ for } l = 1, 2, \dots, \text{width}/8 - 1 \\ 0 & \text{otherwise} \end{cases}$$

$$(Q_{H\bar{B}}f)(i, j) = \begin{cases} f(i, j) - f(i+1, j) & \text{if } i \neq 8l \text{ for } l = 1, 2, \dots, \text{width}/8 - 1 \\ 0 & \text{otherwise} \end{cases}$$

$$Q_B = \|Q_{HB}f\|^2 + \|Q_{VB}f\|^2$$

$$Q_{\bar{B}} = \|Q_{H\bar{B}}f\|^2 + \|Q_{V\bar{B}}f\|^2$$

$$E_s(f) = \left(\|Q_{HB}f_l\|^2 + \|Q_{VB}f_l\|^2 \right) + \beta \left(\|Q_{H\bar{B}}f_l\|^2 + \|Q_{V\bar{B}}f_l\|^2 \right)$$

Regularized Iterative Restoration

Временная регуляризация

$$MFD(f_k, f_l) = \sum_{i=1}^{width} \sum_{j=1}^{height} \left[f_l(i, j) - f_k(i + m^{(i,j)}, j + n(i, j)^{(i,j)}) \right]^2$$

$(m^{(i,j)}, n(i, j)^{(i,j)})$ - вектор движения пикселя (i, j)

$$E_t(f_l) = \sum_{k \neq l} MFD(f_k, f_l)$$

$$E_t(f_l) = \|f_l - f_l^{MC}\|^2$$

Regularized Iterative Restoration

Решение

- Цель

$$J(f) = \|f - g\|^2 + \lambda_s E_s(f) + \lambda_t E_t(f)$$

- Решение

$$f_i^{k+1} = f_i^k + \alpha \left\{ g - \left[I + \lambda_{S_1} Q_B^T Q_B + \lambda_{S_2} Q_{\bar{B}}^T Q_{\bar{B}} + \lambda_t (f_i - f_i^{MC}) \right] f_i^k \right\}$$

Regularized Iterative Restoration

Многокадровое восстановление

$$\tilde{f} = [f_1^T, f_2^T, \dots, f_L^T]^T$$

$$J(\tilde{f}) = \left(\sum_{l=1}^L \|f_l - g_l\|^2 \right) + \lambda_s E_s(\tilde{f}) + \lambda_t E_t(\tilde{f})$$

$$E_s(\tilde{f}) = \sum_{l=1}^L \left[\lambda_1 \left(\|Q_{HB} f_l\|^2 + \|Q_{VB} f_l\|^2 \right) + \lambda_2 \left(\|Q_{H\bar{B}} f_l\|^2 + \|Q_{V\bar{B}} f_l\|^2 \right) \right]$$

$$E_t(\tilde{f}) = \sum_{l=1}^L \|f_l - f_l^{MC}\|^2$$

Regularized Iterative Restoration

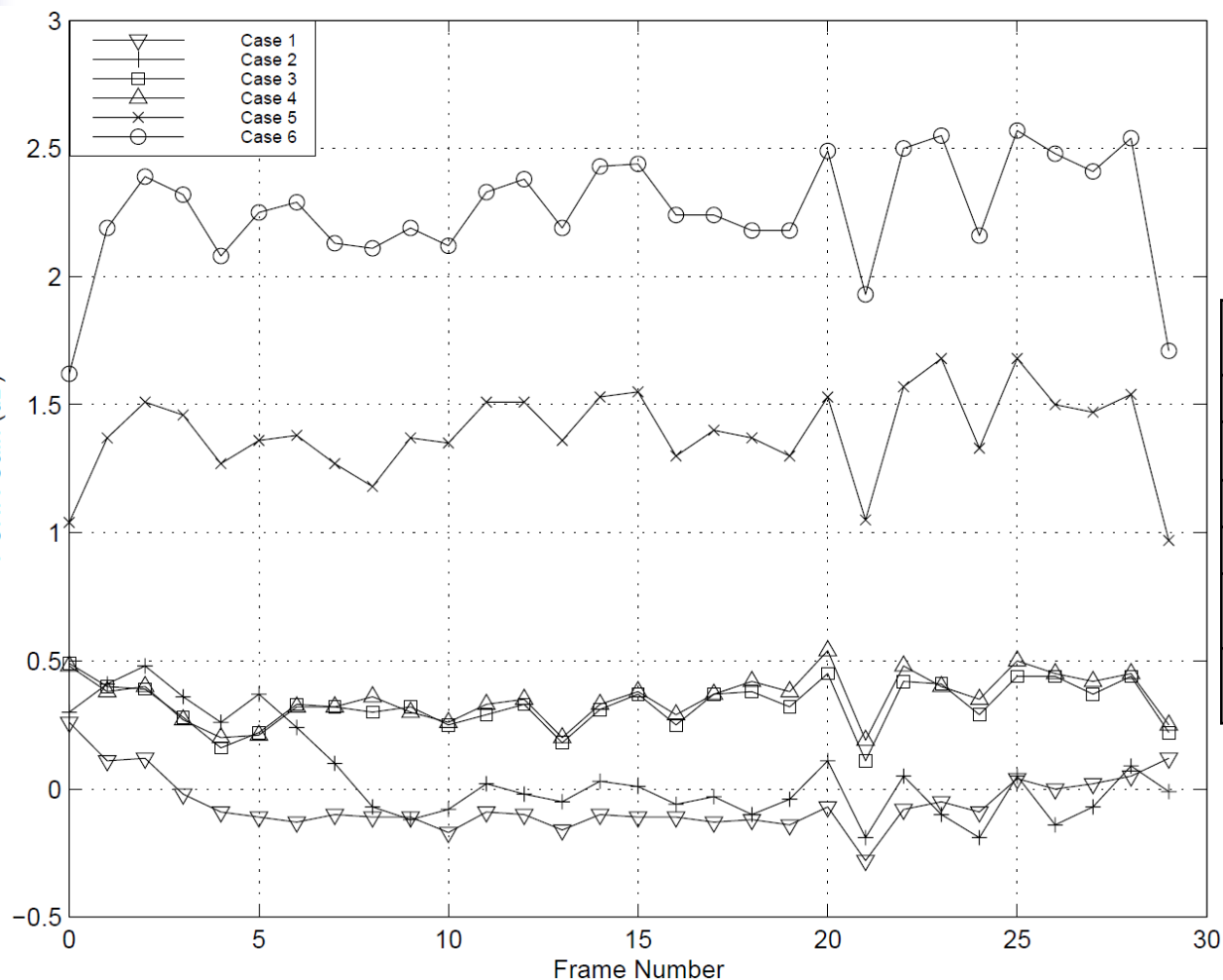
Многокадровое восстановление

$$J(\tilde{f}) = \|\tilde{f} - \tilde{g}\|^2 + \lambda_{S_1} \|\mathcal{Q}_B \tilde{f}\|^2 + \lambda_{S_2} \|\mathcal{Q}_{\bar{B}} \tilde{f}\|^2 + \lambda_t \|\tilde{f} - \tilde{f}^{MC}\|^2$$

$$\tilde{f}^{k+1} = \tilde{f}^k + \alpha \left\{ \tilde{g} - \left[\left(I + \lambda_{S_1} \mathcal{Q}_B^T \mathcal{Q}_B + \lambda_{S_2} \mathcal{Q}_{\bar{B}}^T \mathcal{Q}_{\bar{B}} \right) \tilde{f}^k + \lambda_t \frac{\partial \|\tilde{f} - \tilde{f}^{MC}\|}{\partial \tilde{f}} \Big|_{\tilde{f} = \tilde{f}^k} \right] \right\}$$

Regularized Iterative Restoration

Примеры работы



# of case	
1	spatial only
2	16x16 ME
3	4x4 ME
4	dense 4x4 ME
5	bidirectional 4x4 ME
6	dense bidirectional 4x4 ME

Regularized Iterative Restoration

Примеры работы



dense 4x4 ME

Regularized Iterative Restoration

Примеры работы



dense bidirectional 4x4 ME

Regularized Iterative Restoration

Оптимизация

$$J(f) = \|f - g\|^2 + \lambda_s \|Q_B f\|^2 + \lambda_t \|f - f^{MC}\|$$

- цель минимизации

$$J(f) = \|f - g\|^2 + \lambda_s \sum_{i,j} \varphi(Q_{B_{i,j}} f) + \lambda_t \|f - f^{MC}\|$$

- идея: добавить вспомогательную переменную, не изменяющую минимум J

$$\varphi(t) = \inf_b [bt^2 + \psi(b)]$$

$$b(t) = \frac{\varphi'(t)}{2t}$$

- дополнительная переменная

$$J^*(f, b) = \|f - g\|^2 + \lambda_s \sum_{i,j} [b_{i,j} (Q_{B_{i,j}} f)^2 + \psi(b)] + \lambda_t \|f - f^{MC}\|$$

- новая цель минимизации

Regularized Iterative Restoration

Оптимизация

Алгоритм:

Initialization : $f^0 = g$

repeat {

$b^{n+1} = \min J^*(f^n, b^n)$ with f^n fixed :

$$b^{n+1} = \partial(Q_B f^n) / \partial f^n$$

$f^{n+1} = \min J^*(f^n, b^{n+1})$ with b fixed

} *Until convergence*

Минимизация может быть выполнена методом градиентного спуска

Regularized Iterative Restoration

Оптимизация

$$J^*(f^n, b^{n+1}) = \sum_{i,j} (f_{i,j}^n - f_{i,j}^{n+1})^2 + \lambda_s \sum_{i,j} [b_{i,j}^{n+1} (Q_{B_{i,j}} f^{n+1})^2 + \psi(b_{i,j}^{n+1})] + \lambda_t \sum_{i,j} (f_{i,j}^{n+1} - f_{i,j}^{MC})^2$$

$$f_{i,j}^{n+1} = \frac{1}{1 + \lambda_t} x_{i,j}^n - \frac{\lambda_s b_{i,j}^{n+1}}{(1 + \lambda_t)(1 + 2\lambda_s b_{i,j}^{n+1} + \lambda_t)} (f_{i,j}^n - f_{i,j+1}^n) + \frac{\lambda_t (1 + \lambda_s b_{i,j}^{n+1} + \lambda_t)}{(1 + \lambda_t)(1 + 2\lambda_s b_{i,j}^{n+1} + \lambda_t)} f_{i,j}^{mc} + \frac{\lambda_s \lambda_t b_{i,j}^{n+1}}{(1 + \lambda_t)(1 + 2\lambda_s b_{i,j}^{n+1} + \lambda_t)} f_{i,j+1}^{mc}$$

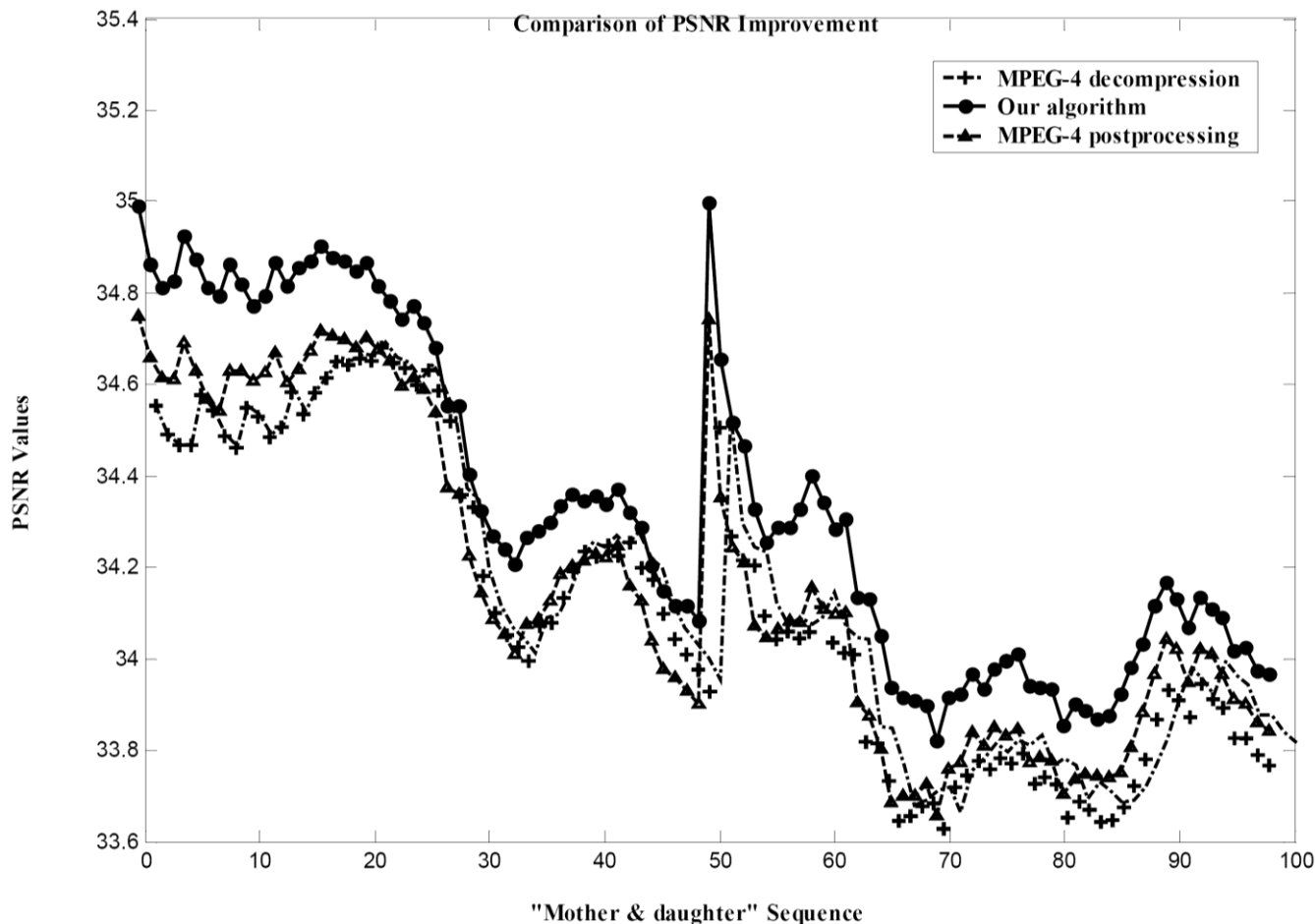
Regularized Iterative Restoration

Пример работы



Regularized Iterative Restoration

Пример работы



Regularized Iterative Restoration

Пример работы

Resolution	Sequence	QP	PSNR_Y [dB] (average of 100 frames)			
			Before post-processing	After Post-processing		
				MPEG-4	Proposed	
CIF (352x288)	Akiyo	15	34.70	34.82	34.91	
		18	33.71	33.83	33.96	
		20	33.23	33.36	33.44	
	Mother & daughter	15	34.40	34.43	34.56	
		18	33.63	33.65	33.79	
		20	33.19	33.20	33.34	
	Hall	10	34.96	35.18	35.23	
		15	32.84	33.10	33.30	
		18	31.82	32.08	32.22	
		20	31.25	31.49	31.65	
	QCIF (176x144)	Carphone	10	33.55	33.61	33.78
			15	31.51	31.55	31.75
18			30.57	30.60	30.75	
20			30.02	30.04	30.16	
News		15	30.42	30.51	30.82	
		18	29.46	29.36	29.65	
		20	28.78	28.87	29.04	

A Coding Artifacts Removal Algorithm Based On Spatial And Temporal Regularization. Susu Yao, Genan Feng, Xiao Lin, Keng Pang Lim and Weisi Lin. 2003.



Regularized Iterative Restoration

- Преимущества
 - Высокое качество восстановления
- Недостатки
 - Очень медленная работа
 - Сложен в реализации



Заключение

■ Рассмотрены методы

- Adaptive Fuzzy Post-Filtering
- DCT Re-application
- Support Vector Regression
- Modified Mean-Removed Classified Vector Quantization
- Регуляризация

Литература

- A Coding Artifacts Removal Algorithm Based On Spatial And Temporal Regularization. Susu Yao, Genan Feng, Xiao Lin, Keng Pang Lim and Weisi Lin. 2003.
- Artifact reduction of compressed color images using modified mean-removed classified vector quantization. Jim Zone-Chang Lai, Yi-Ching Liaw, and Winston Lo. Journal of the Chinese Institute of Engineers, Vol. 27, No. 5, pp. 747-751 (2004)
- Compressed Video Enhancement using Regularized Iterative Restoration Algorithms. Passant Vatsalya Karunaratne. Evanston, Illinois. 1999
- Compression Artifact Reduction Using Support Vector Regression. Sanjeev Kumar, Truong Nguyen, Mainak Biswas. ICIP 2006
- Adaptive Fuzzy Post-Filtering for Highly Compressed Video. Hao-Song Kong, Yao Nie, Anthony Vetro, Huifang Sun, Kenneth E. Barner. ICIP 2004.
- Enhancement of JPEG-Compressed Images by Re-application of JPEG. Aria Nosratinia. Department of Electrical Engineering, University of Texas at Dallas, Richardson. 2002.
- A Tutorial on Support Vector Regression. Alex J. Smola† and Bernhard Schölkopf. 2003
- Application Of The Motion Vector Constraint To The Regularized Enhancement Of Compressed Video. C. Andrew Segall And Aggelos K. Katsaggelos. 2001



Вопросы

