A Video Haze Removal System on Heterogeneous Cores

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IEEE Global Conference on Signal and Information Processing

16 December 2015, 14:00 → 15:20

Haze removal problem

Hazy image

Haze-removed image

Single-image haze removal methods

Method	Resolution	Time
Tan (2008) [1]	600×400	5-7 minutes
Fattal (2008) [2]	512×512	35 seconds
He *et al.* (2011) [3]	600×400	10-20 seconds
Ke *et al.* (2013) [4]	600×400	760 milliseconds

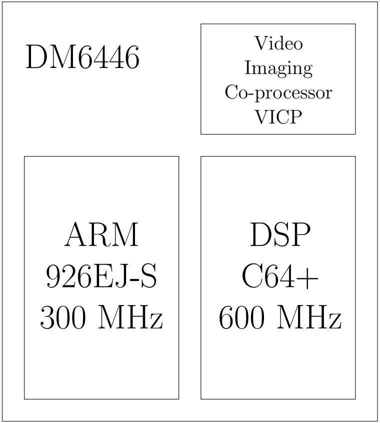
A system in [5] based on DM6446 SoC, using ARM and DSP cores processes a full D1 720×480 frame in 1.7 seconds.

Problem description

Video processing application on target platform

- Very high input/output data rate (30×10^6 sample/sec.).
- High computational cost (many processes required for each frame depending on the problem).
- High memory requirements.

DM6446 DaVinci SoC



TMS320DM6446 platform, where we propose a distribution of the tasks of the algorithm among the heterogeneous processor cores: ARM, DSP, and VICP.

Haze imaging model

$$\mathbf{I}(\mathbf{x}) = \mathbf{J}(\mathbf{x})t(\mathbf{x}) + \mathbf{A}(1 - t(\mathbf{x})),$$

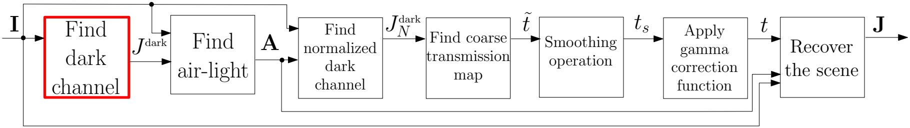
$\mathbf{I}$ is the observed scene (hazy image)
$\mathbf{J}$ is the scene radiance (haze free image)
t is the medium transmission
$\mathbf{A}$ is the atmospheric light
$\mathbf{x} = (x, y)$ are the horizontal and vertical positions of the pixel.

Single-image haze removal methods

Dark channel prior-based methods [3, 4, 5]

- Simple and effective.
- Provides good results in most cases.

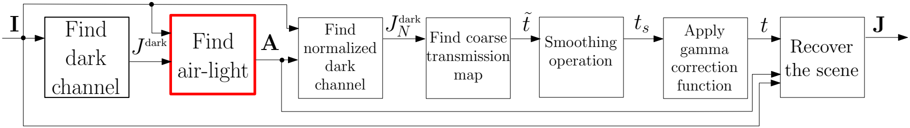
Ke *et al.*'s [4] method block diagram



Find dark channel:

$$J^{\text{dark}}(\mathbf{x}) = \min_{c \in \{r,g,b\}} (I^c(\mathbf{x}))$$

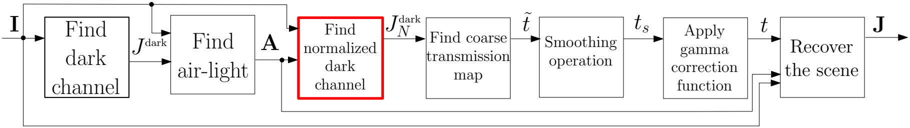
Ke *et al.*'s [4] method block diagram



Calculate the air-light:

Find pixels with the highest 0.1% values in J^{dark}. The sum of the three color channel values in I of these pixels is calculated. Finally, the pixel corresponding to the maximum sum is selected as A

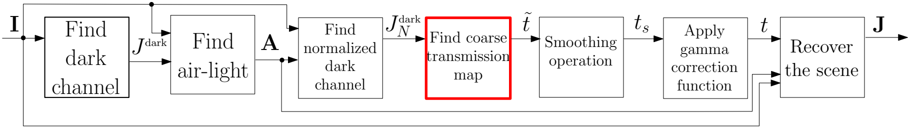
Ke *et al.*'s [4] method block diagram



Find the normalized dark channel:

$$J_N^{\text{dark}}(\mathbf{x}) = \min_{c \in \{r,g,b\}} \left(\frac{I^c(\mathbf{x})}{A^c}\right)$$

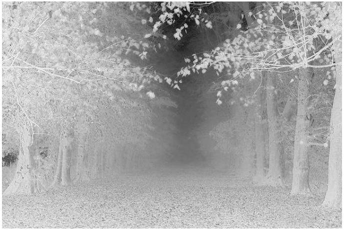
Ke *et al.*'s [4] method block diagram



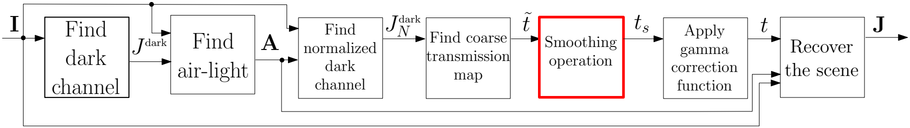
Estimate the coarse transmission:

$$\tilde{t}(\mathbf{x}) = 1 - (\omega \times J_N^{\text{dark}}(\mathbf{x})).$$

where ω is set to 0.95.



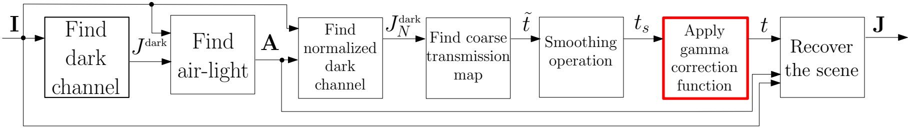
Ke *et al.*'s [4] method block diagram



Apply a smoothing operation:

$$t_s(x) = \frac{1}{n} \sum_{\mathbf{y} \in \Omega(\mathbf{x})} \tilde{t}(\mathbf{y}).$$

Ke *et al.*'s [4] method block diagram

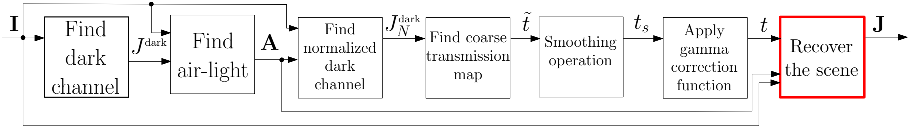


Apply a gamma correction function:

$$t(\mathbf{x}) = (t_s(\mathbf{x}))^{\gamma},$$

where γ is set to 0.6.

Ke *et al.*'s [4] method block diagram



Recover the scene radiance:

$$\mathbf{J}(\mathbf{x}) = \frac{\mathbf{I}(\mathbf{x}) - \mathbf{A}}{\max(t(\mathbf{x}), 0.1)} + \mathbf{A}$$

Time profiling for Ke *et al.*'s [4] algorithm

Task	Execution time
Convert from YC_bC_r to RGB	12 ms
Find the dark channel J^{dark}	12 ms
Find air-light **A**	10 ms
Find normalized dark channel J_N^{dark}	12 ms
Find the coarse transmission map $\tilde{t}$	430 ms
Apply moving average filter to obtain t_s filter	4 ms
Apply gamma correction function to obtain t	1433 ms
Recover the scene radiance **J**	75 ms
Convert from RGB to YC_bC_r	12 ms
Total	2000 ms

Modified haze removal algorithm

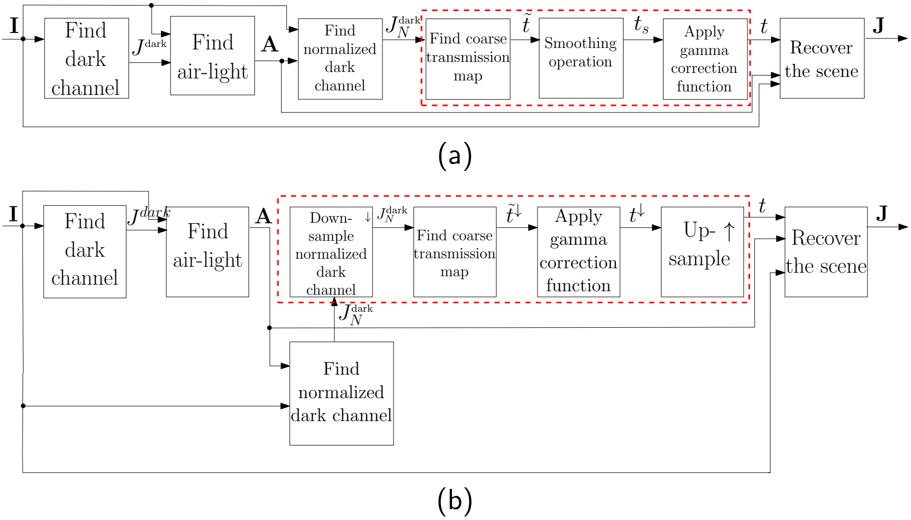
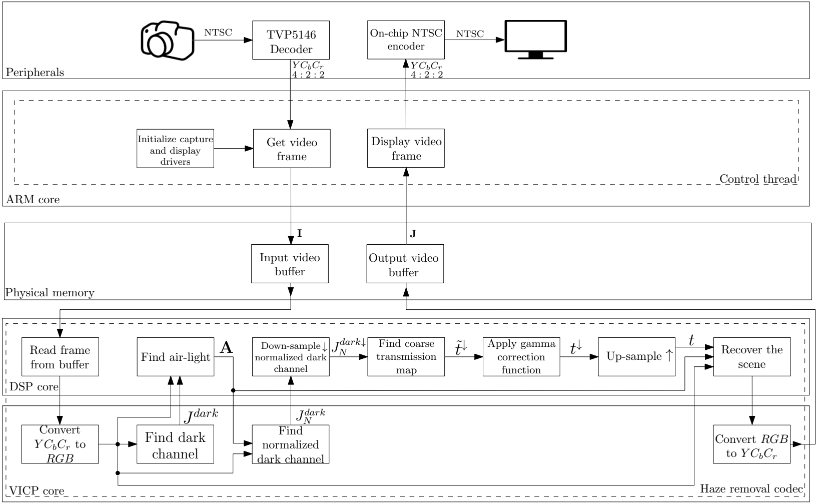


Figure: (a) Ke *et al.*, (b) proposed.

Proposed distribution of algorithmic tasks among ARM, DSP, VICP cores of DM6446

Task	ARM	DSP	VICP
Initialize capture and display drivers	✓		
Get video frame	✓		
Convert from YC_bC_r to RGB			✓
Find dark channel			✓
Find air-light		✓	
Find normalized dark channel			✓
Down-sample the normalized dark channel		✓	
Find the coarse transmission map		✓	
Apply gamma correction function		✓	
Up-sample the transmission map		✓	
Recover the scene		✓	
Convert from RGB to YC_bC_r			✓
Display video frame	✓		

Proposed haze removal software architecture on the target heterogeneous multi-cores



Code optimization

Optimization technique	Benefits
Using fixed-point data representation instead of floating-point data representation	DSP core in the TMS320DM6446 is a fixed-point core
Minimizing the number of memory accesses by using minimal data types whenever it is possible	More data will be stored into the cache and the number of operations per cycle will increase
Division operations are converted into multiplications	Division operations take more execution cycles than multiplication operations
Using shortcuts in programming *i.e.*, using `x += 1` instead of `x = x + 1`	The number of MOV instructions is reduced
Setting γ to 0.5 instead of 0.6 in $t(\mathbf{x}) = (t_s(\mathbf{x}))^\gamma$	The gamma correction function will be implemented as square root
The optimized functions from the libraries provided by TI are used	Enable the SIMD feature of the DSP

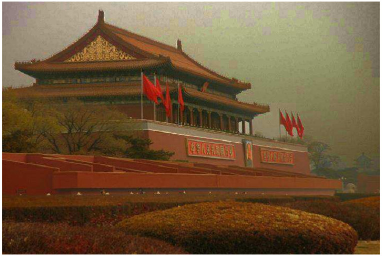
Time profiling for the proposed algorithm

Task	Execution time
Convert from YC_bC_r to RGB	12 ms
Find the dark channel J^{dark}	12 ms
Find air-light **A**	10 ms
Find normalized dark channel J_N^{dark}	12 ms
Down-sample normalized dark channel $J_N^{\text{dark}\downarrow}$	6 ms
Find the coarse transmission map	65 ms
Apply gamma correction function to obtain t	102 ms
Up-sample the transmission map t	6 ms
Recover the scene radiance **J**	75 ms
Convert from RGB to YC_bC_r	12 ms
Total	320 ms

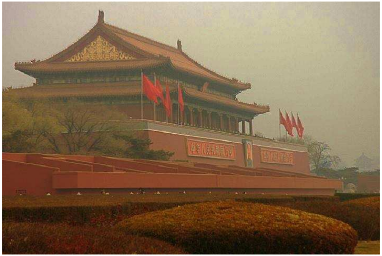
Quality verification

- The implementation of He *et al.*, Ke *et al.*, and the proposed algorithm have been made using MATLAB 8.3 on core i5 personal computer with 4GB RAM using 720×480 images.

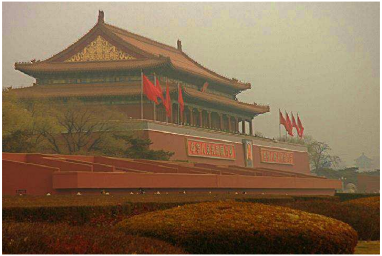
(a)



(b)



(c)



(d)

Figure: Temple image: (a) hazy image, (b) [3], (c) [4], (d) proposed.

(a)

(b)

(c)

(d)

Figure: Temple image: (a) hazy image, (b) [3], (c) [4], (d) proposed.

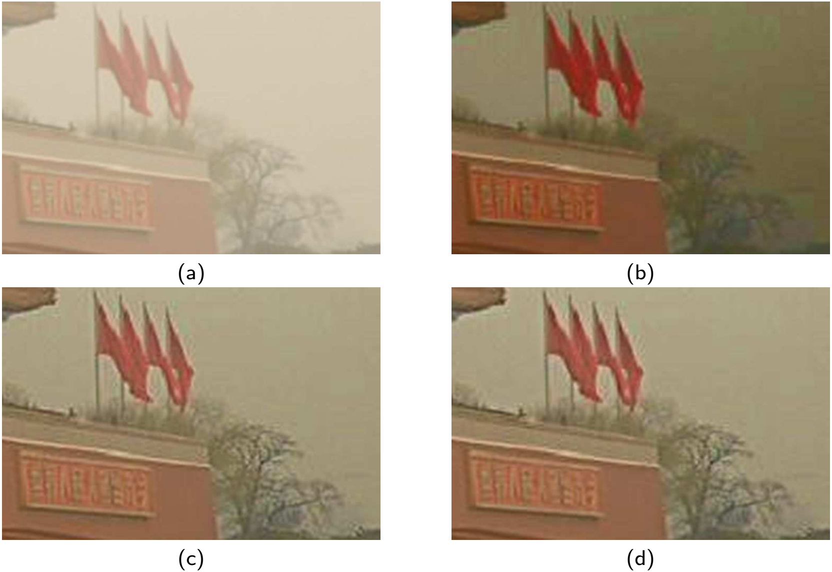
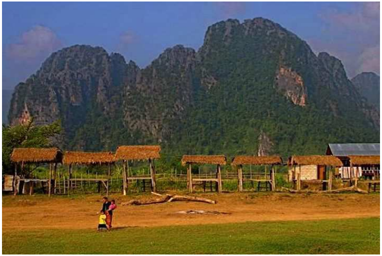


Figure: Temple image zoomed version: (a) hazy image, (b) [3], (c) [4], (d) proposed.

(a)

(b)

(c)



(d)

Figure: Mountain image: (a) hazy image, (b) [3], (c) [4], (d) proposed.


(a)


(b)


(c)


(d)

Figure: Mountain image: (a) hazy image, (b) [3], (c) [4], (d) proposed.

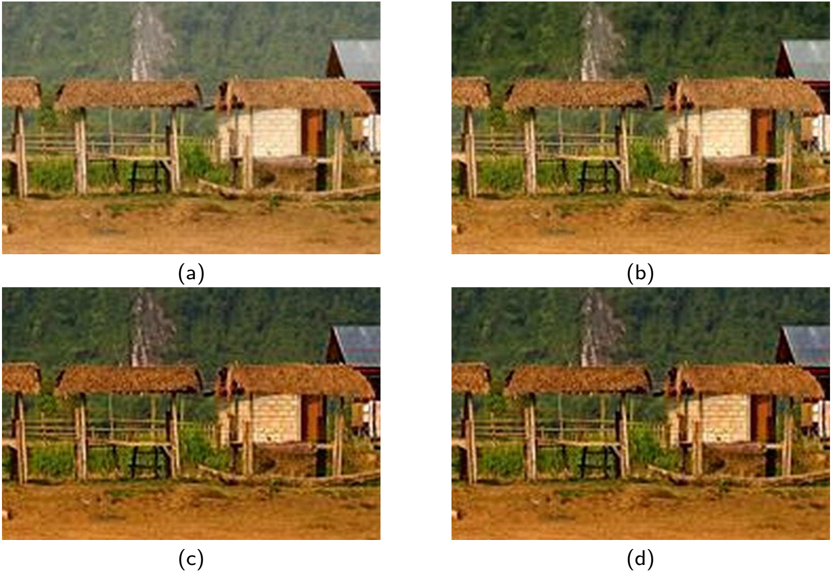


Figure: Mountain image zoomed version: (a) hazy image, (b) [3], (c) [4], (d) proposed.

Evaluation metrics [6]

1. Execution time (the lower the better)
2. The rate of new visible edges (e) (the higher the better)
3. The quality of the contrast restoration ($\bar{r}$) (the higher the better)
4. The number of pixels which are saturated (σ) (the lower the better)

Execution times in seconds for images using different haze removal algorithms on personal computer

Image	[3]	[4]	Proposed algorithm
Temple	70.432	1.346	**1.003**
Mountain	70.370	1.337	**1.003**

Descriptors for sample images using different haze removal algorithms

Descriptor	Algorithm	Temple	Mountain
e	[3]	**0.5954**	0.2566
	[4]	0.5204	**0.3013**
	proposed	0.4986	0.2739
$\bar{r}$	[3]	1.3516	1.1404
	[4]	1.3271	1.037
	proposed	**1.3839**	**1.1925**
σ (%)	[3]	**0**	**0**
	[4]	**0**	0.0030
	proposed	**0**	0.0066

Experimental results for the proposed system

Video execution time of the proposed system is presented and compared to Ke *et al.* [4] and Khodary *et al.* [5] on TMS320DM6446.

Figure: Proposed video haze removal system: (a) DM6446 DaVinci evaluation module, (b) hazy video source, and (c) removed-haze video output.

Output frame rate (fps) of different haze removal systems

Video input	[4]	[5]	Proposed system
NTSC (720×480 at 30 fps)	0.5	0.58	**3.2**

Conclusions and future works

- Development on multi-core embedded system have to consider some aspects:
  1. Adapting the algorithm for the embedded platform.
  2. Distribution of algorithmic tasks based of the nature of the task and the core.
  3. Optimizing the code for each task.
- The proposed system provides 3.2 fps for full D1 resolution.

Bibliography

[1] Robby Tan. Visibility in bad weather from a single image. In *Proc. IEEE Conf. Computer Vision Pattern Recognition*, pages 1–8, 2008.

[2] Raanan Fattal. Single image dehazing. *ACM Trans. on Graphics*, 27 (3):72:1–72:9, 2008.

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[4] NaiCyun Ke, JuChin Chen, and z. Real-time visibility restoration from a single image. In *Proc. IEEE Int. Conf. Image Processing*, pages 923–927, 2013.

[5] Ahmed Khodary and Hussein Aly. A new image-sequence haze removal system based on DM6446 DaVinci processor. In *Proc. IEEE Global Conf. Signal and Information Processing*, pages 871–874, 2014.

[6] Nicolas Hautiere, Jean Tarel, Didier Aubert, and Eric Dumont. Blind contrast enhancement assessment by gradient ratioing at visible edges. *Image Analysis & Stereology Journal*, 27(2):87–95, 2008.

Questions