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Curve based Fast Detail Enhancement for Biomedical Images

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AIOP Research Seminar

Research Project

“Curve Based Fast Detail Enhancement for Biomedical Images” has been successfully accepted at 16th International Conference on Computer Vision and Applications (**VISAPP 2021**).

It has been published in the proceedings, placed in the SCITEPRESS Digital Library (**DOI: 10.5220/0010250203370344**). I was the speaker to make an oral presentation of this paper.

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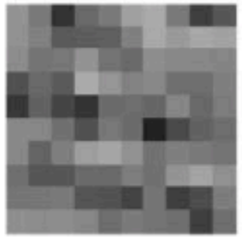
What is an image ?

- 2-dimensional matrix of intensity (gray or color) values

Set of Intensity values

Image coordinates are integers

$$I(u,v) \in \mathbb{P} \quad \text{and} \quad u,v \in \mathbb{N}.$$



$F(x,y)$

→

148	123	52	107	123	162	172	123	64	89	⋯
147	130	92	95	98	130	171	155	169	163	⋯
141	118	121	148	117	107	144	137	136	134	⋯
82	106	93	172	149	131	138	114	113	129	⋯
57	101	72	54	109	111	104	135	106	125	⋯
138	135	114	82	121	110	34	76	101	111	⋯
138	102	128	159	168	147	116	129	124	117	⋯
113	89	89	109	106	126	114	150	164	145	⋯
120	121	123	87	85	70	119	64	79	127	⋯
145	141	143	134	111	124	117	113	64	112	⋯
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	

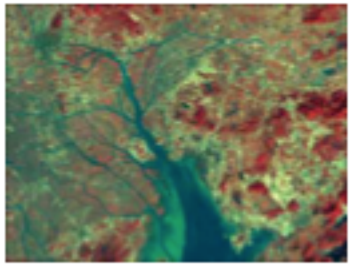
$I(u,v)$

Example of Images

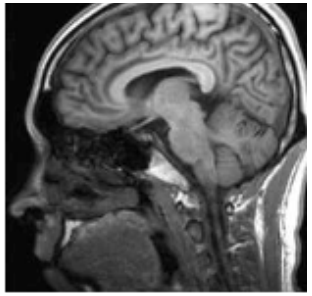
(a) Natural image

(b) Document image

(c) Synthetic image



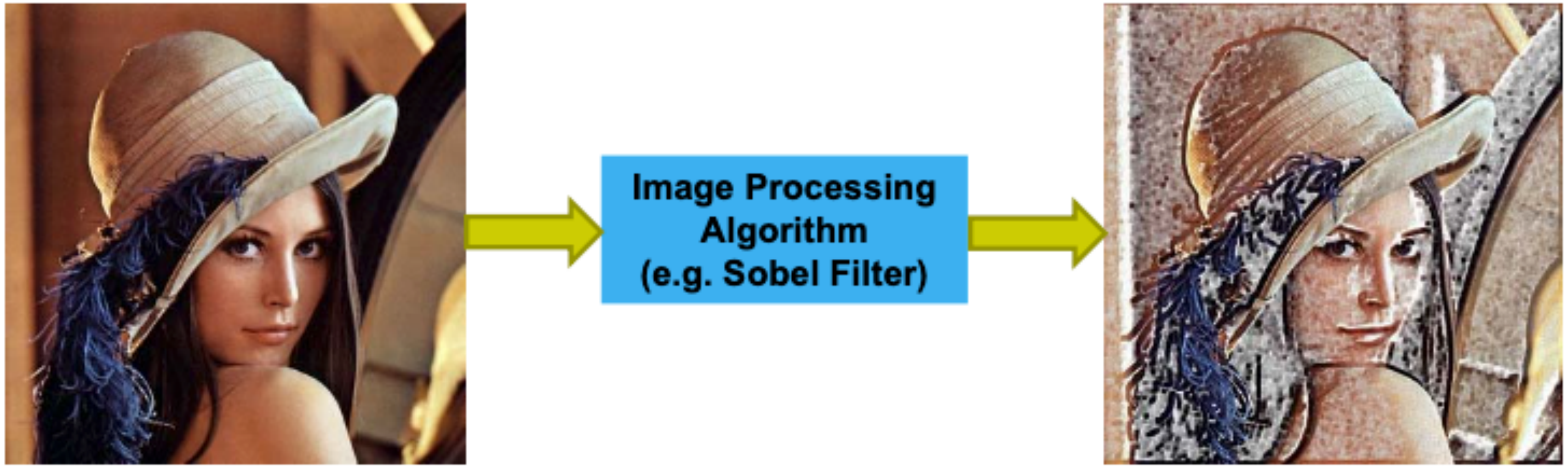
(d) Satellite image



(e) MRI (magnetic strengt

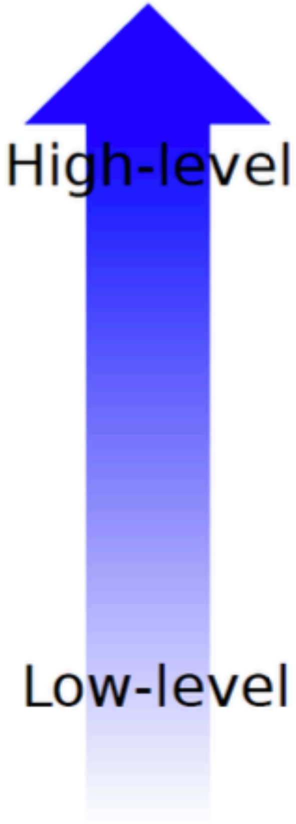
What is image processing?

- Algorithms that alter an input image to create new image
- Input is image, output is image



Original Image *Processed Image*

Relationship with other fields



Computer Vision

Object detection, recognition, shape analysis, tracking
Use of Artificial Intelligence and Machine Learning

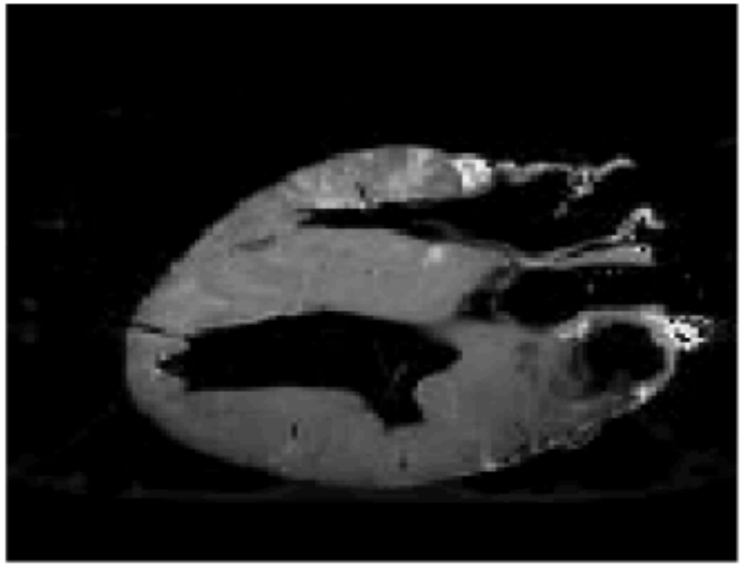
Image Analysis

Segmentation, image registration, matching

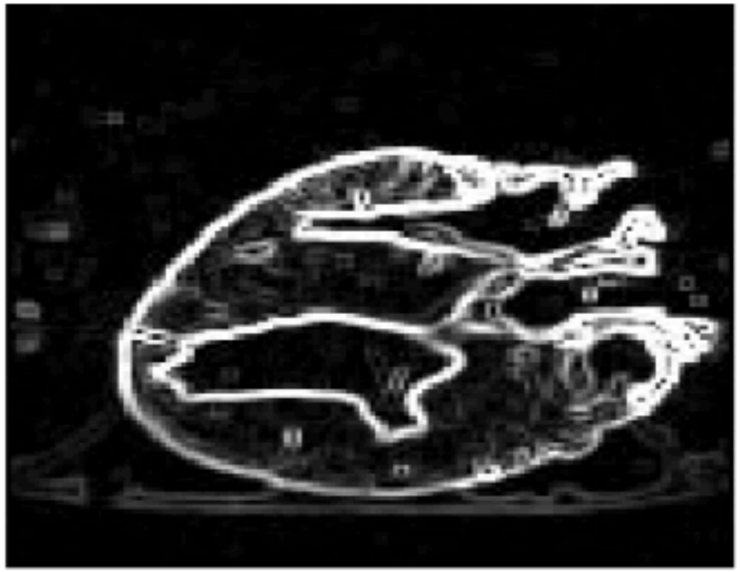
Image Processing

Image enhancement, noise removal, restoration,
feature detection, compression

Applications of image processing: Medicine



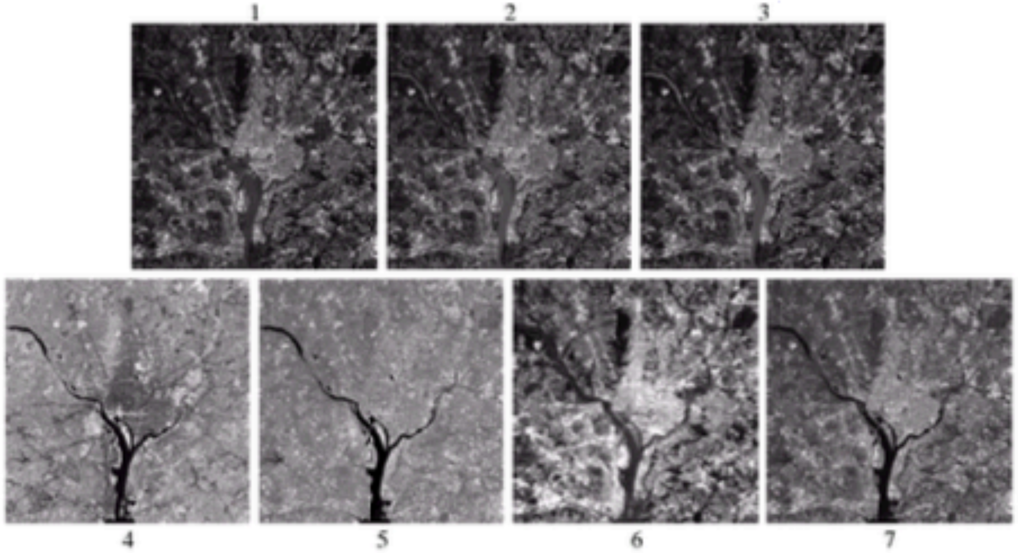
Original MRI Image of a Dog Heart

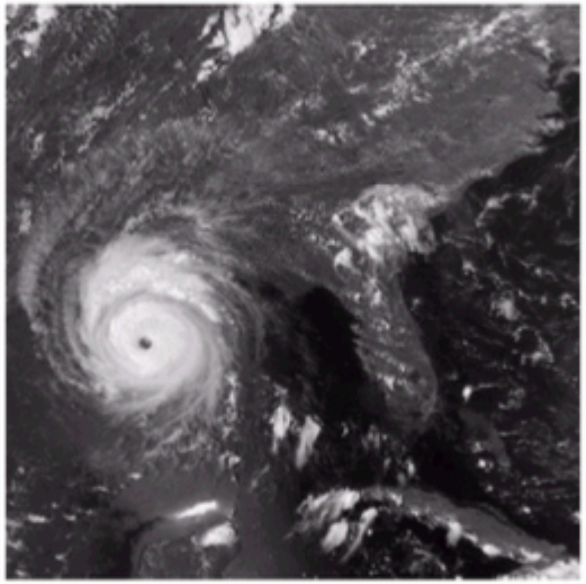


Edge Detection Image

Gonzalez & Woods, Digital Image Processing (2002)

Applications of image processing: Geographic information Systems

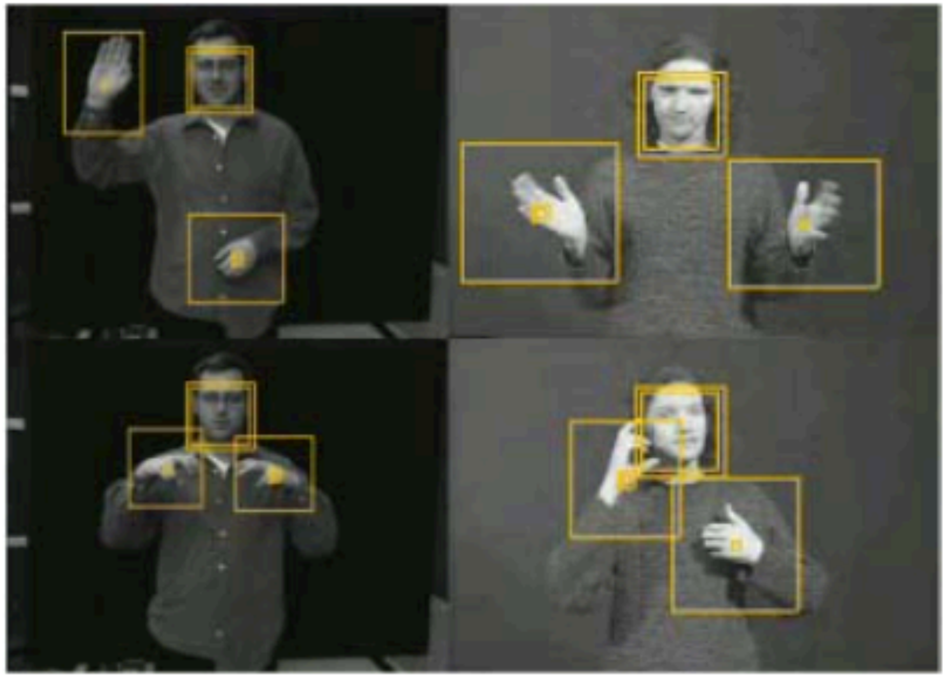




Gonzalez & Woods, Digital Image Processing (2002)

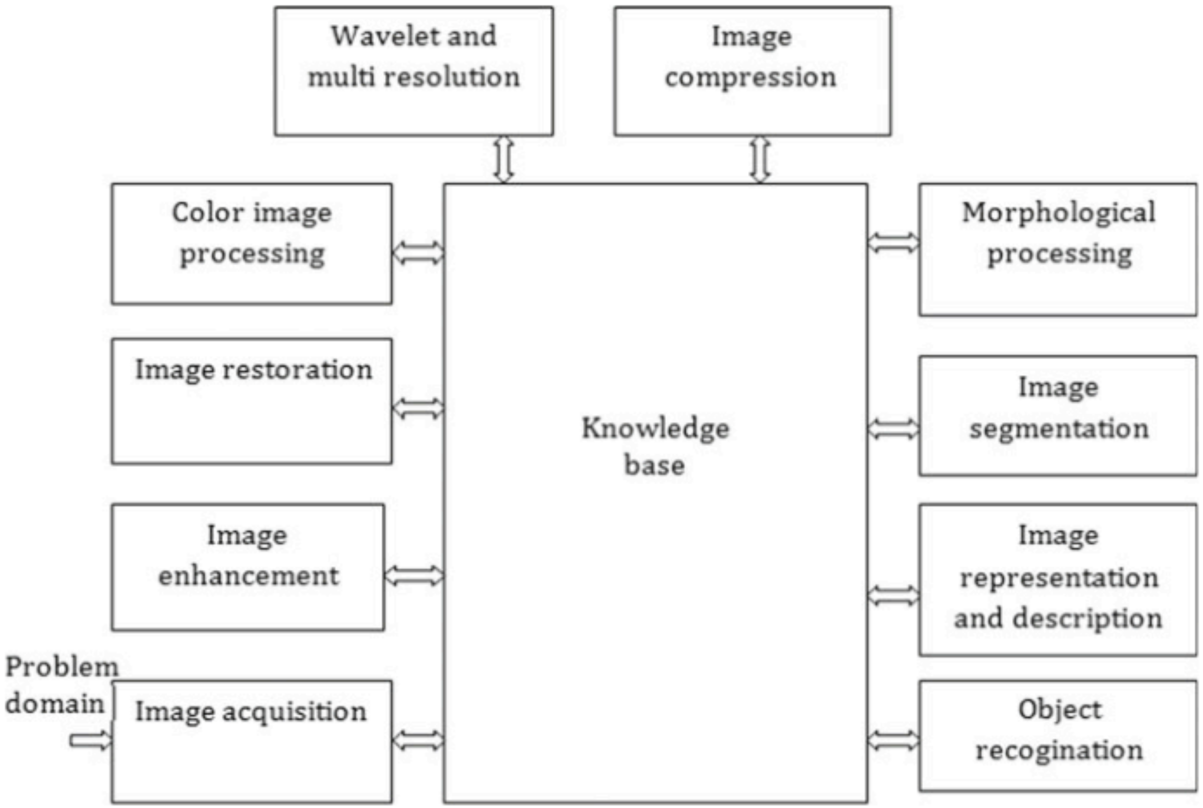
Applications of image processing: HCI

- Face recognition
- Gesture recognition



Gonzalez & Woods, Digital Image Processing (2002)

Steps of image processing



Somal, Simran. "Image Enhancement Using Local and Global Histogram Equalization Technique and Their Comparison.", 2020.

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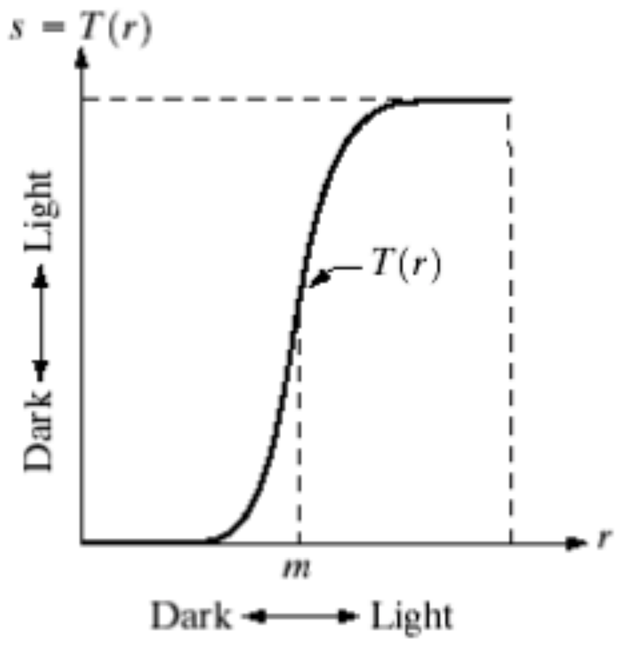
Intensity Transformation

Intensity Levels

- For a typical person, the eyes can adapt to a wide range of light intensity levels. The human visual system can perceive approximately 10^{10} different light intensity levels.
- At a particular instance, the eyes respond to a much narrower range. We are often interested in the extend that our eyes can detect changes in light intensity levels.
- The actual brightness perceived is a logarithmic function of the light intensity arriving at the eyes.
- The perceived intensity of a region is also related to the light intensities of the regions surrounding it.

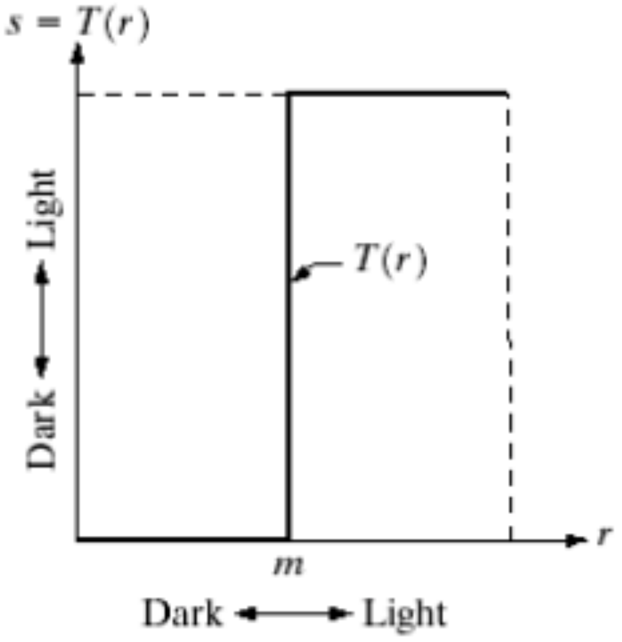
Intensity Transformation Example: Contrast stretching



The Chinese University of Hong Kong, Shen Zhen, ELE4512, Digital Image Processing, Spring 2019

Intensity Transformation

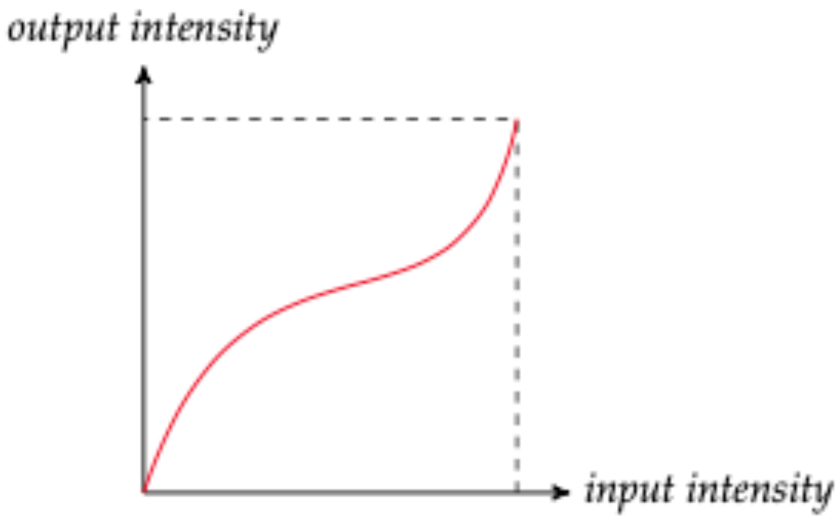
Intensity Transformation Example: Thresholding



Intensity Transformation

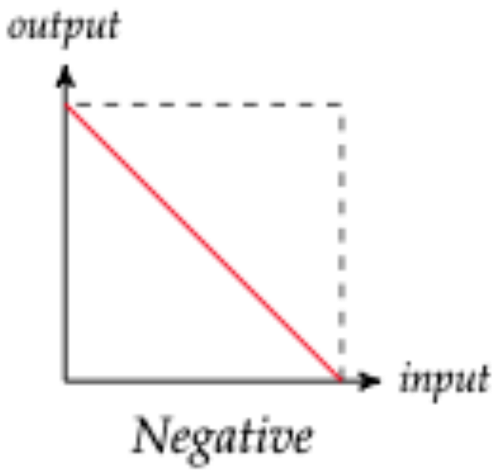
Gray-level mapping

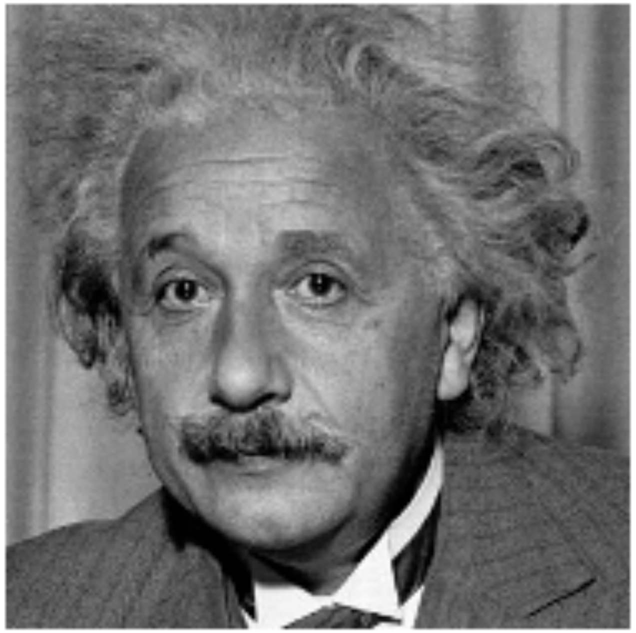
- For every pixel, we change the intensity from value input to output.
- The algorithm can be represented by an input-output plot.



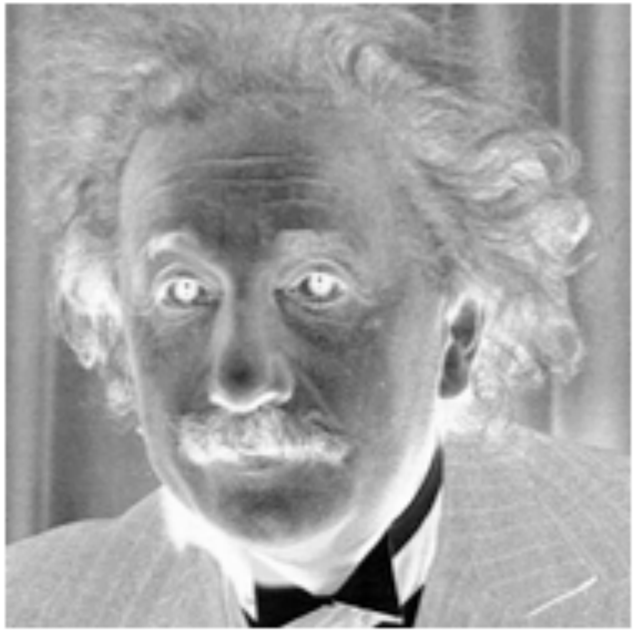
Intensity Transformation Functions

- Negative Transformation





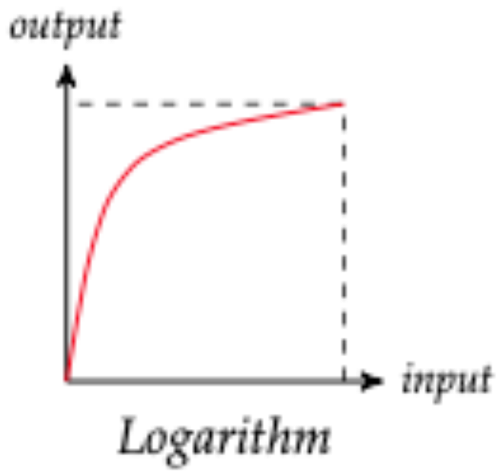
Original



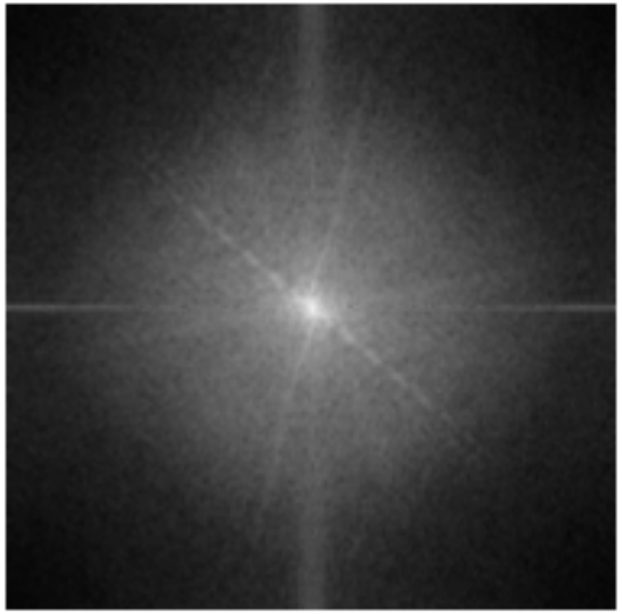
Modified

Intensity Transformation Functions

- Logarithm Transformation



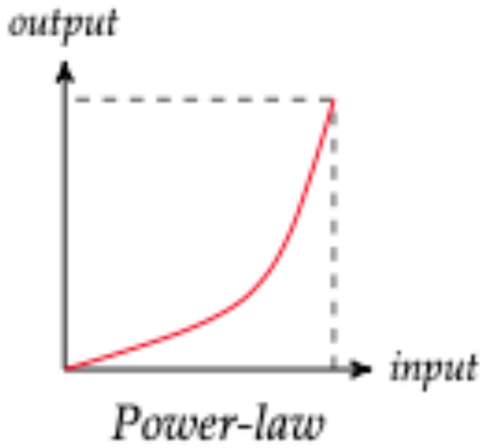
Original



Modified

Intensity Transformation Functions

- Power-law Transformation



Original

Modified

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- Image Enhancement
  - Image Processing
  - Intensity Transformation
  - **Histogram Processing**
  - Otsu's Method
  - Image Enhancement Algorithms
- Our proposed work 'Curve based fast detail enhancement for biomedical images'
  - Background & Task
  - Dataset
  - Methodology
  - Results

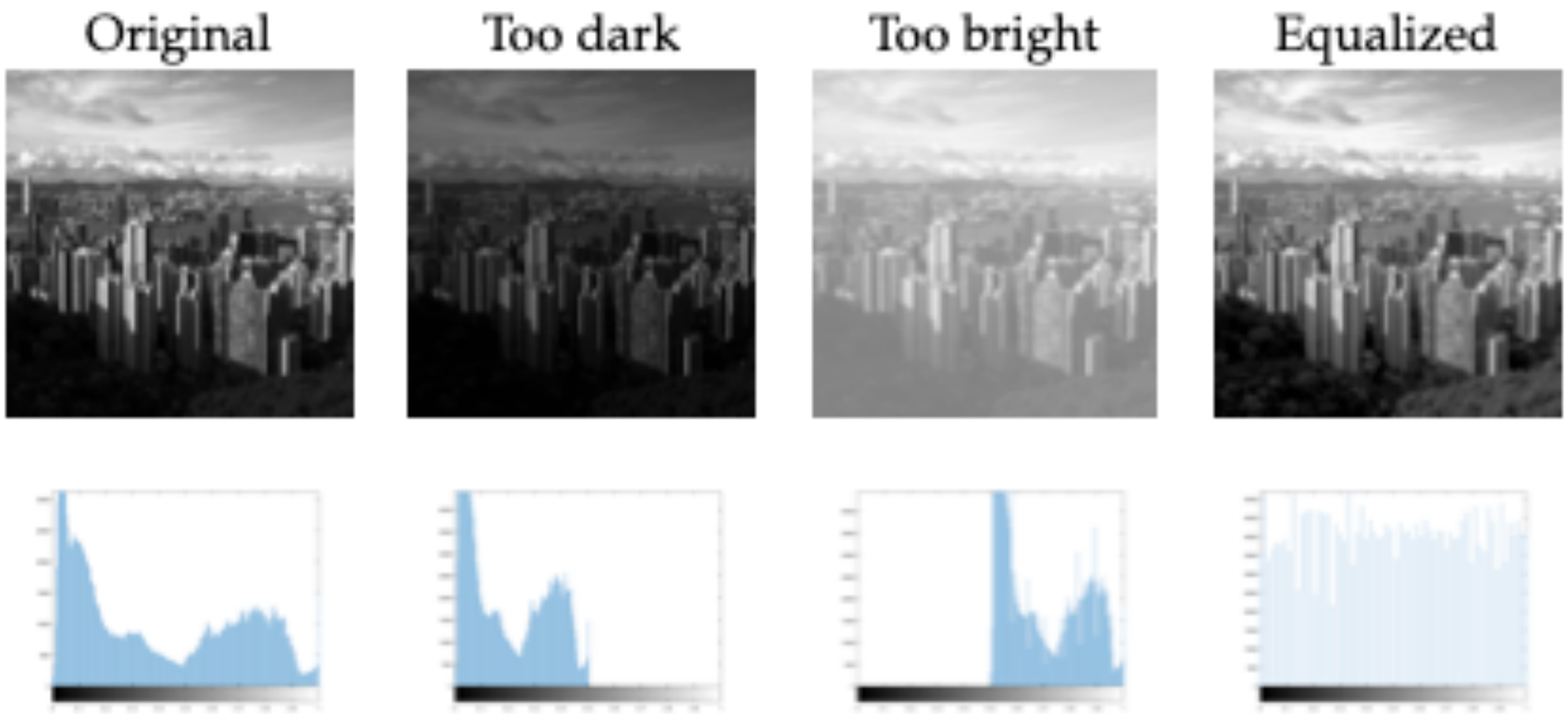
Histogram Processing

Histogram

- Each pixel has a value (intensity). By collecting all the pixels together, we can form a histogram.
- Histograms plots how many times (frequency) each intensity value in image occurs.
- The histogram can be helpful to **provide the ‘curve’ for gray-level mapping**.

Histogram Processing

Histogram



Histogram Processing

Significance of Histogram

- The basics for many spatial domain processing techniques.
- Often used for image enhancement.
- Information contained in the histograms is also useful for image compression.

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Otsu's Method

Image Thresholding

- Image thresholding is used to binarize the image based on pixel intensities.
- If the intensity of a pixel in the input image is greater than a threshold, the corresponding output pixel is marked as white (foreground), and if the input pixel intensity is less than or equal to the threshold, the output pixel location is marked black (background).

Otsu's Method

Automatic Global Thresholding

1. Process the input image

2. Obtain image histogram (distribution of pixels)

3. Compute the threshold value T

4. Replace image pixels into white in those regions, where saturation is greater than T and into the black in the opposite cases.

Otsu's Method

Otsu's Thresholding Concept

- Otsu's method is a way to automatically determine the threshold (auto thresholding)
- The method processes image histogram, segmenting the objects by minimisation of the variance on each of the classes.
- The histogram of such image contain two clearly expressed peaks, which represent different ranges of intensity values.

Otsu's Method

- Let $\{0, 1, 2, \ldots, L\text{-}1\}$ denote the intensities of a $M\text{x}N$ image and n_i the number of pixels with intensity i.
- The normalized histogram has components:

$$p_i = \frac{n_i}{MN}, \quad \sum_{i=0}^{L-1} p_i = 1, \quad p_i \geq 0$$

- Suppose we choose a threshold k to segment the image into two classes:
  - C_1 with intensities in the range $[0, k]$,
  - C_2 with intensities in the range $[k+1, L\text{-}1]$.

Otsu's Method (cont.)

- The probabilities of classes C_1 and C_2:

$$P_1(k) = \sum_{i=0}^{k} p_i, \quad P_2(k) = \sum_{i=k+1}^{L-1} p_i = 1 - P_1(k)$$

- The mean intensity of class C_1 :

$$m_1(k) = \sum_{i=0}^{k} iP(i \mid C_1) = \sum_{i=0}^{k} i \frac{P(C_1 \mid i)P(i)}{P(C_1)} = \frac{1}{P_1(k)} \sum_{i=0}^{k} ip_i$$

Intensity i belongs to class C_1 and $P(C_1 \mid i) = 1$

Otsu's Method (cont.)

- Similarly, the mean intensity of class C_2:

$$m_2(k) = \sum_{i=k+1}^{L-1} iP(i \mid C_2) = \sum_{i=k+1}^{L-1} i \frac{P(C_2 \mid i)P(i)}{P(C_2)} = \frac{1}{P_2(k)} \sum_{i=k+1}^{L-1} ip_i$$

- Mean image intensity:

$$m_G = \sum_{i=0}^{L-1} ip_i = P_1(k)m_1(k) + P_2(k)m_2(k)$$

- Cumulative mean image intensity (up to k):

$$m(k) = \sum_{i=0}^{k} ip_i$$

Otsu's Method (cont.)

- Between class variance:

$$\sigma_B^2(k) = P_1(k)[m_1(k) - m_G]^2 + P_2(k)[m_2(k) - m_G]^2$$

- With some manipulation we get:

$$\sigma_B^2(k) = \frac{[m_G P_1(k) - m(k)]^2}{P_1(k)[1 - P_1(k)]}$$

- The value of k is selected by sequential search as the one maximazing:

$$k^* = \max_{0 \le k \le L-1} \{\sigma_B^2(k)\}$$

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Image Enhancement Algorithms

Image Enhancement

- The manipulation or transformation of an image, with the aim of increasing its usefulness or visual appearance.
- For example, modification of intensity values so as to increase contrast
- If an image is too dark, then it is hard to see bright spots, it seems like details are hidden under this darkness.
- So, certainly visually, by enhance the image, there's considerably more information that can be observed in the processed enhanced image.

Image Enhancement Algorithms

Image Enhancement

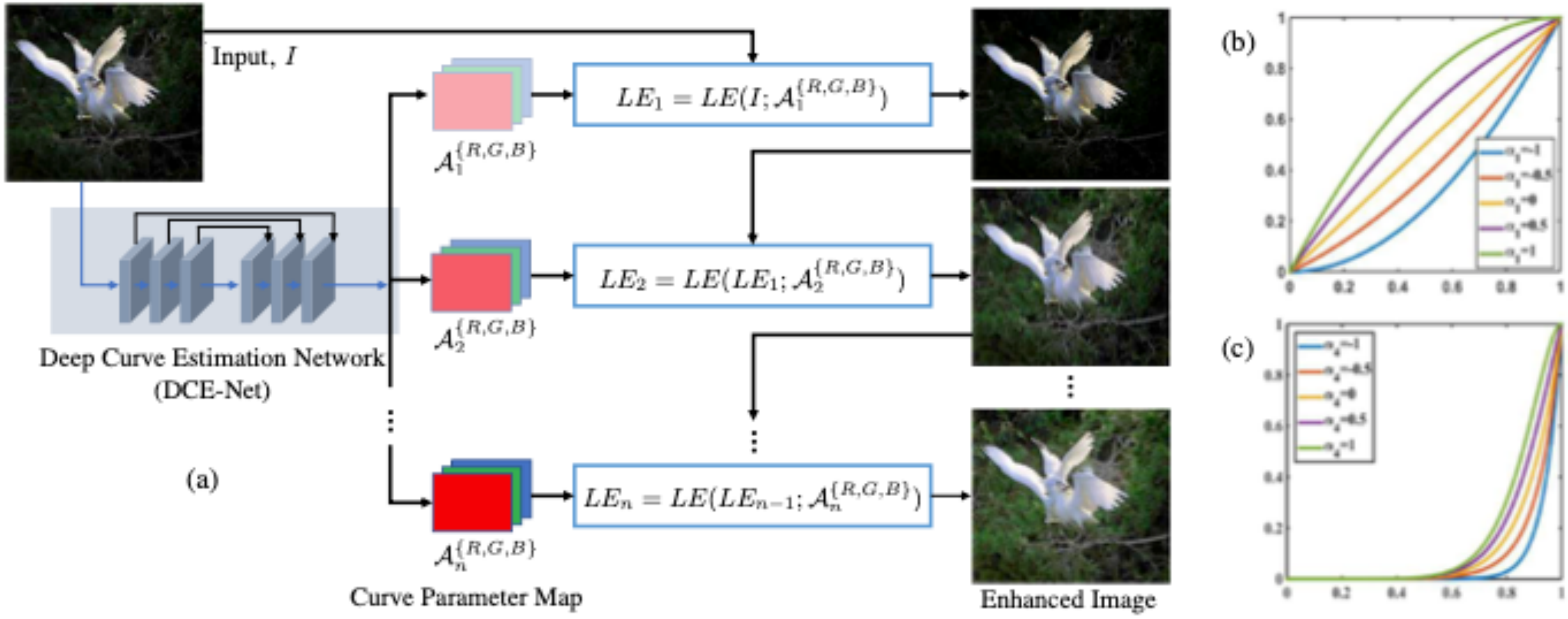
- **Conventional Methods**: HE-based methods, etc.
- **Data-Driven Methods**: CNN-based methods, GAN-based methods, etc.

Zero-Reference Deep Curve Estimation (Zero-DCE)

- Zero-Reference Deep Curve Estimation (Zero-DCE), which formulates light enhancement as a task of image-specific curve estimation with a **deep network**.
- Trains a lightweight deep network, DCE-Net, to estimate pixel-wise and high-order curves for dynamic range adjustment of a given image.

Guo, C., Li, C., Guo, J., Loy, C. C., Hou, J., Kwong, S., & Cong, R. Zero-reference deep curve estimation for low-light image enhancement. CVPR 2020

Zero-Reference Deep Curve Estimation (Zero-DCE)



Guo, C., Li, C., Guo, J., Loy, C. C., Hou, J., Kwong, S., & Cong, R. Zero-reference deep curve estimation for low-light image enhancement. CVPR 2020

Image Enhancement Algorithms

Histogram Equalization

- Spreading out the frequencies in an image is a simple way to improve dark images

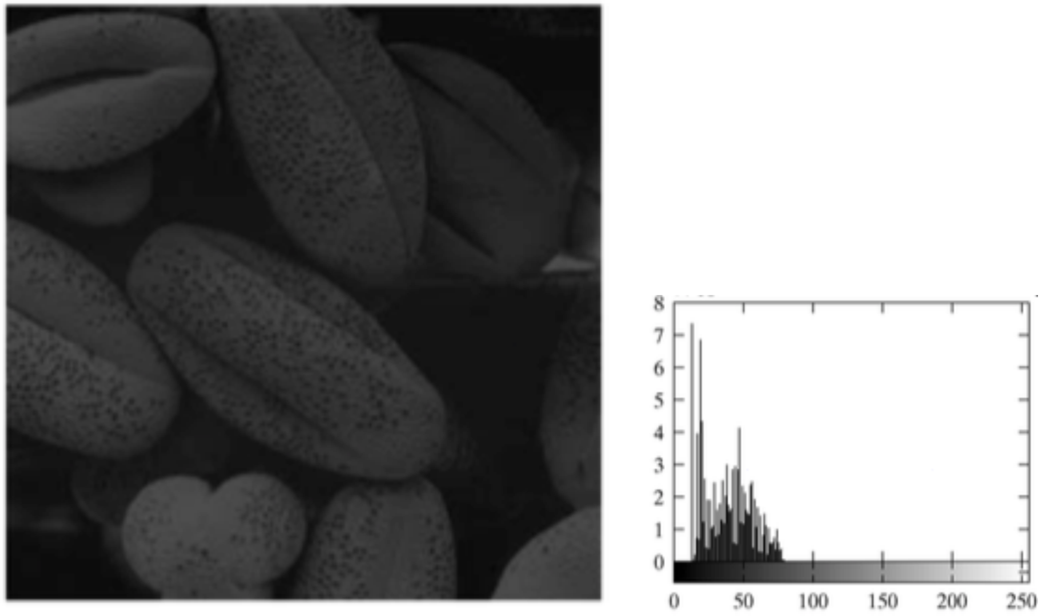
  - r_k: input intensity
  - s_k: processed intensity
  - k: the intensity range (e.g 0.0 – 1.0)

processed intensity → $s_k = T(r_k)$ ← input intensity

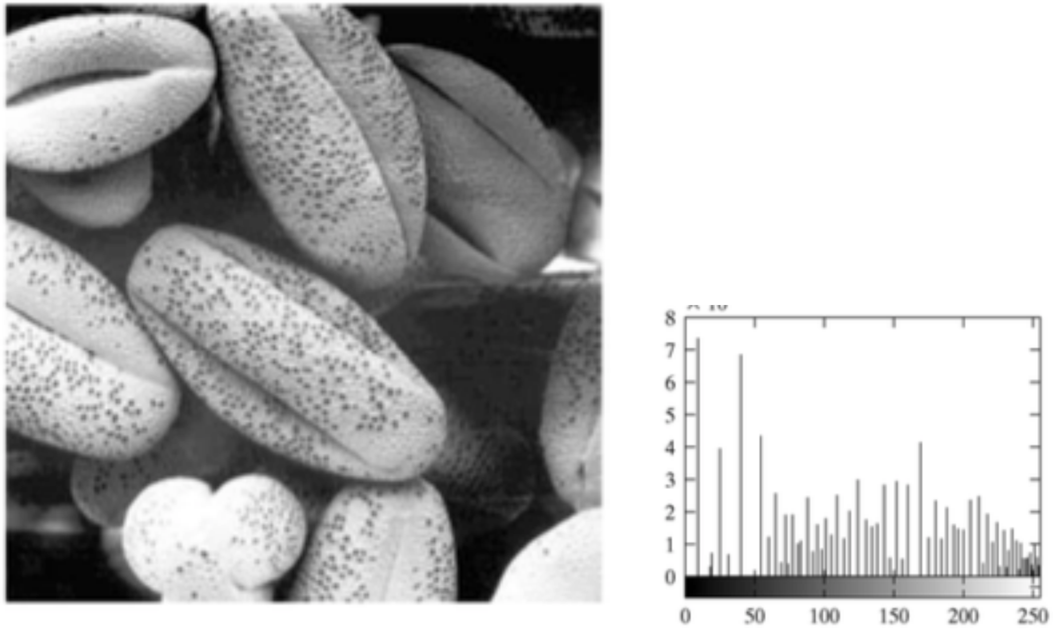
↑ Intensity range (e.g 0 – 255)

Image Enhancement Algorithms

Histogram Equalization



Before



After

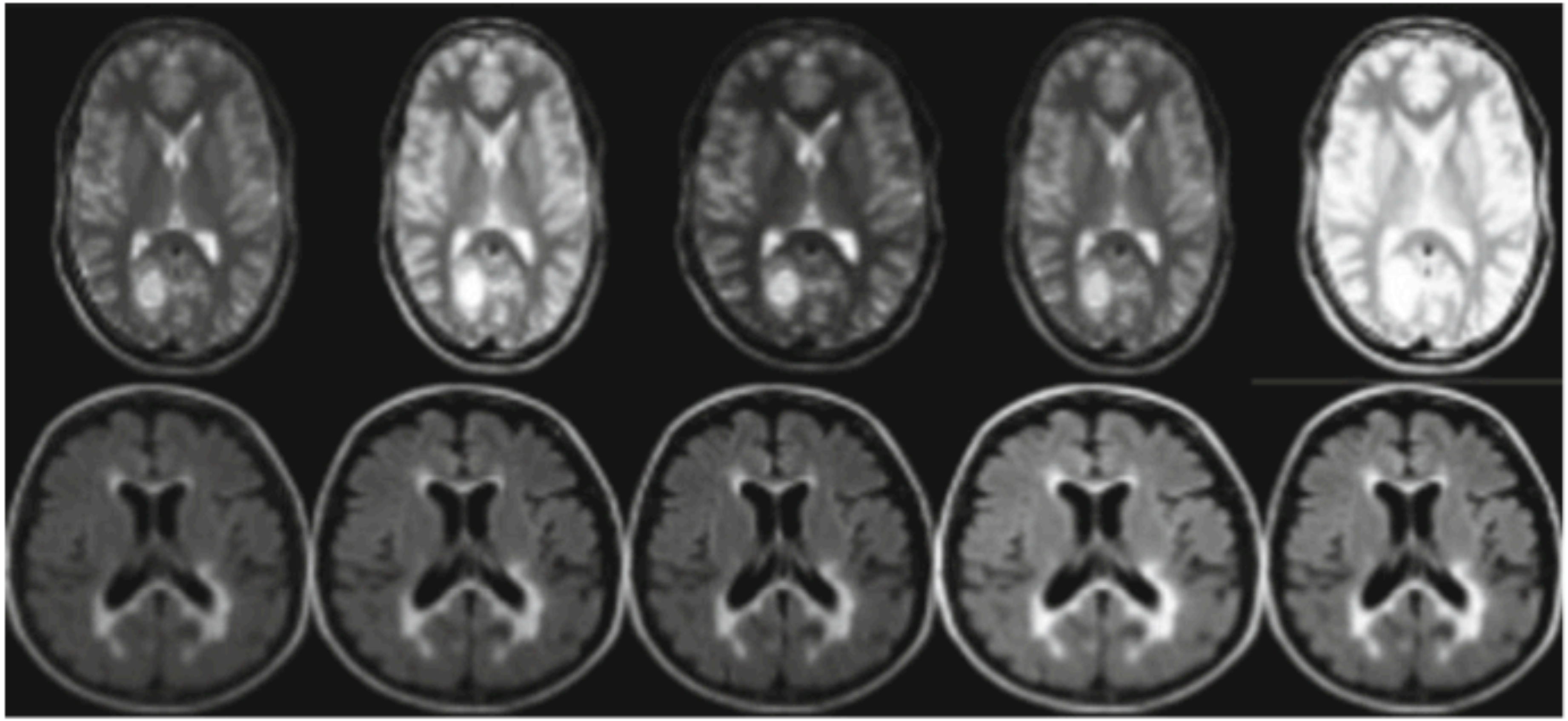
The Chinese University of Hong Kong, Shen Zhen, ELE4512, Digital Image Processing, Spring 2019

Global Histogram Equalization

- The histogram of the whole input image is used to compute the histogram transformation function. As a result, the dynamic range of the image histogram is flattened and stretched. The overall contrast is improved.

Kim, Tae Keun, Joon Ki Paik, and Bong Soon Kang. "Contrast enhancement system using spatially adaptive histogram equalization with temporal filtering." ,1998

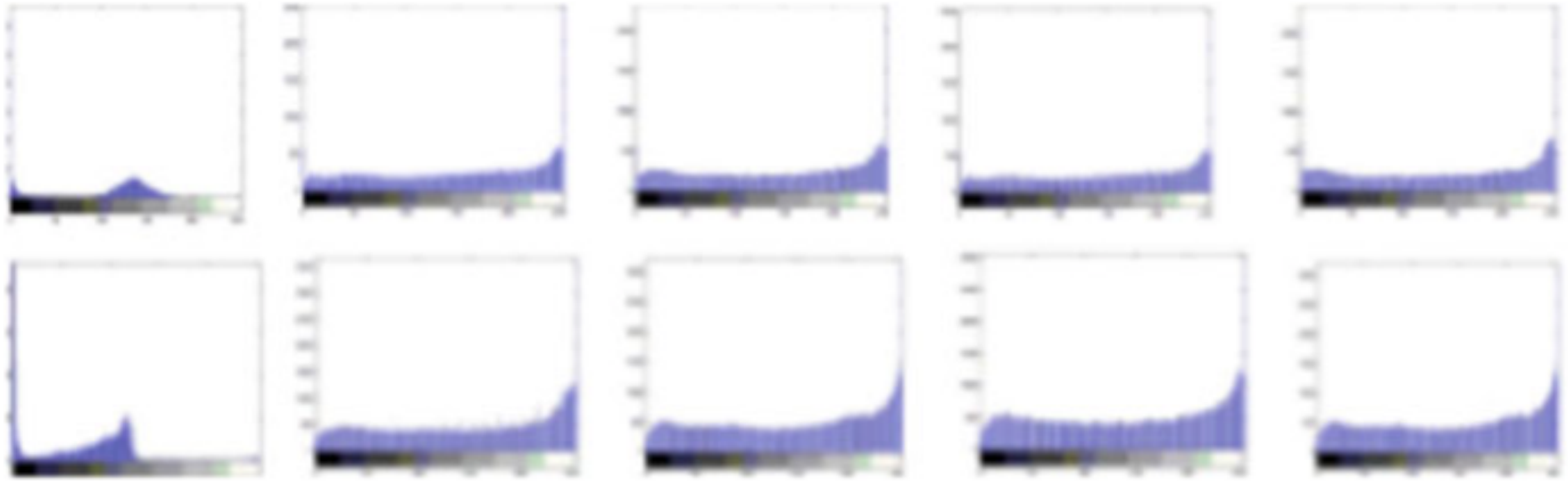
Global Histogram Equalization



Somal, Simran. "Image Enhancement Using Local and Global Histogram Equalization Technique and Their Comparison.", 2020.

Image Enhancement Algorithms

Global Histogram Equalization



Somal, Simran. "Image Enhancement Using Local and Global Histogram Equalization Technique and Their Comparison.", 2020.

Local Histogram Equalization

- LHE implements a block-overlapped technique, which is a sub-block implementation to enhance the image.

- Local histogram equalization entails the processing of three by three neighborhood. So, we take a three by three neighbourhood. We find the mapping that will equalize the histogram in that neighborhood, but we only process the pixel in the center of this three by three neighborhood. Then we move this three by three window to the next pixel, and we repeat this process.

Zhu, Hui, Francis HY Chan, and Francis K. Lam. "Image contrast enhancement by constrained local histogram equalization." ,1999

Image Enhancement Algorithms

Adaptive Histogram Equalization

- Histogram equalization based on a portion of the image, e.g., every non-overlapping 16 × 16 block (tile). Limit contrast expansion in flat regions by clipping values. Smooth blending (bilinear interpolation) between neighbouring tiles.

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  - Results

Background

Motivation

Biomedical image processing can help doctors to diagnose and treat patients.

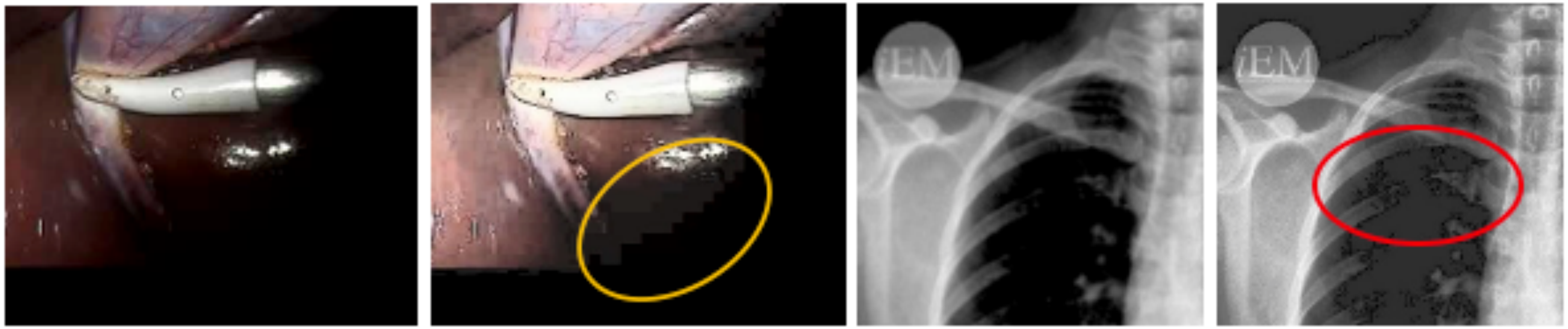
However, low quality and contrast of biomedical images will reduce the doctor's ability to analyse the images, causing subsequent processing difficulties.

- For example:
  - Frames obtained during minimally invasive surgery may have a large shaded region due to less adequate light introduced into the cavity;
  - Dark-coloured tissue may lack details in high contrast frames.
- It is essential to recognise images that need enhancement then adaptively select the targeted dark regions for further processing and **image contrast enhancement**.

Background

Issues of Global histogram equalization (GHE)

- Unwanted colour boundaries in dark region
- Noise around edges are amplified after GHE



input after GHE input after GHE

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Task

Research Objective

This paper proposes a fast method to adaptively **enhance the details** in the **dark regions** of biomedical images, including X-rays, video frames of laparoscopy in minimally invasive surgery (MIS).

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Dataset

Experimental Dataset

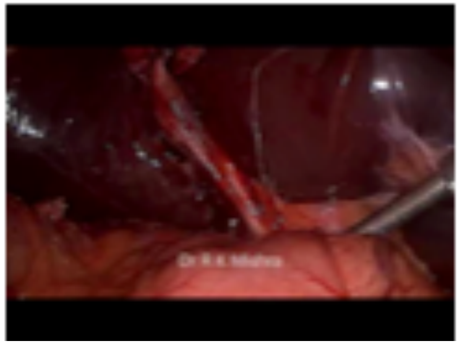
We used laparoscopic surgical frames and X-ray images from website.

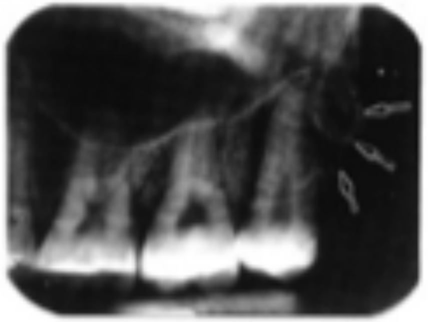
Source:

https://www.youtube.com/watch?v=fs_hJO1RZMs Lap chole basic, around 3:12	https://medtube.net/general-surgery/medical-videos/24250-laparoscopic-cholecystectomy-with-mishra-knot
https://www.youtube.com/watch?v=SpSNewRpdW0 Full length HD Laparoscopic Cholecystectomy with Critical View, around 3:44	https://www.youtube.com/watch?v=O4pO_RXELvE Single incision robotic cholecystectomy, around 1:10
http://drkashi.science/?p=3211, Cefuroxime as a prophylactic antibiotic in laparoscopic cholecystectomy	https://smallanimal.vethospital.ufl.edu/clinical-services/internal-medicine/endoscopy/abdominal-endoscopy/, Abdominal Endoscopy
World J Gastrointest Surg. Feb 27, 2019; 11(2): 62-84, Figure 13	
Voermans, Rogier P., et al. "Hybrid NOTES transgastric cholecystectomy with reliable gastric closure: an animal survival study." Surgical endoscopy 25.3 (2011): 728-736. Figure 1	
https://www.flickr.com/photos/iem-student/29110322657	https://www.waybuilder.net/sweethaven/MedTech/Dental/DentalRad/default.asp?iNum=0303

Dataset

Dataset Example





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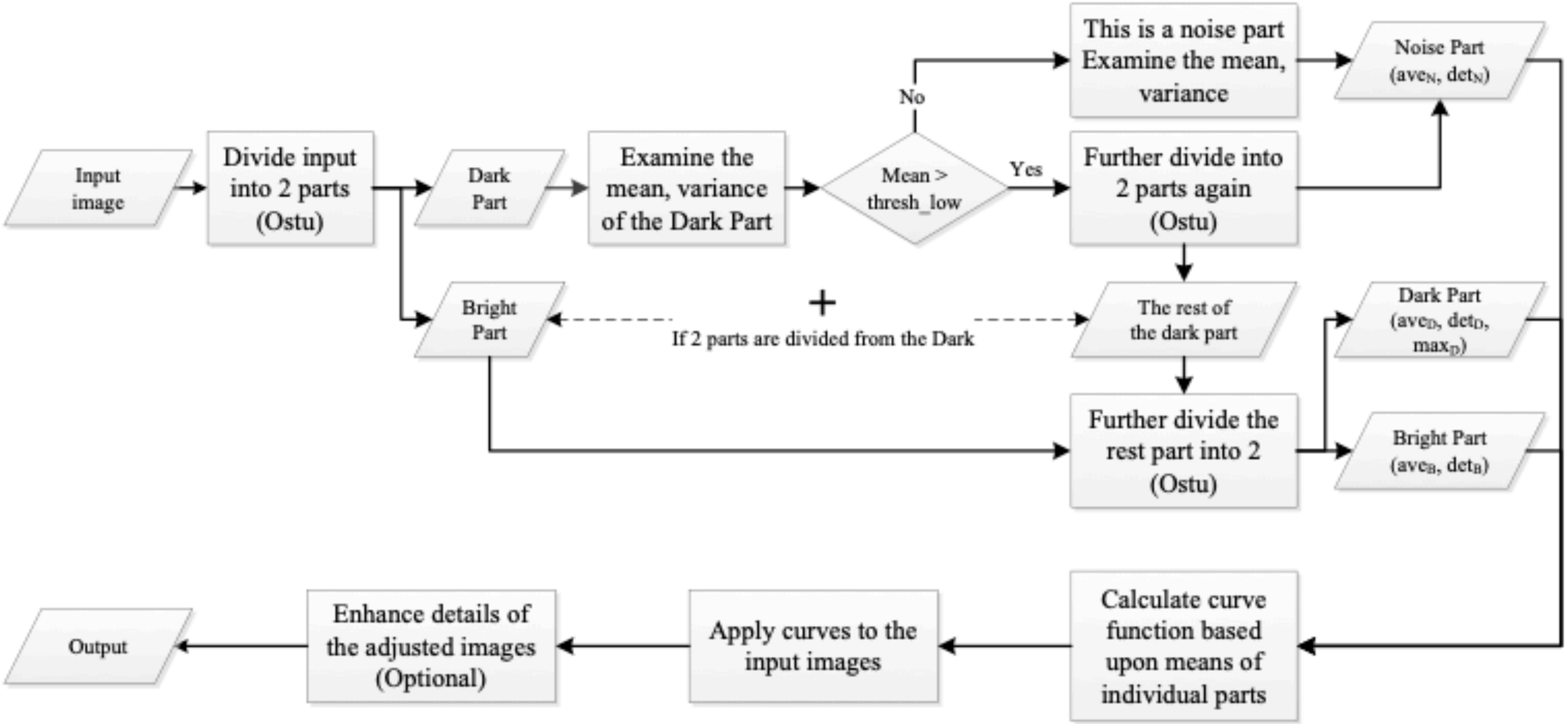
Method

Workflow of the Proposed Algorithm



Fei, R., Weng, Y., Zhang, Y., & Lund, J. (2021). Curve based Fast Detail Enhancement for Biomedical Images.

Method

The Proposed Algorithm

- The **intensity mapping** is done in the **V channel** of HSV colour space, where V = max(R, G, B).
- To calculate the mapping function, the input V channel should be divided into **3 sub-images**, a **noise part** to determine the offset of the function, a relevant dark part to be mapped to a brighter value region and the bright part to determine how bright the dark part can be mapped to.
- To obtain the three parts, **Otsu threshold** is applied to the input channel, which output 2 sub-images where the inter-class variance of the histogram of the two sub-images are maximised.

Method

The Proposed Algorithm (cont.)

After the initial thresholding:

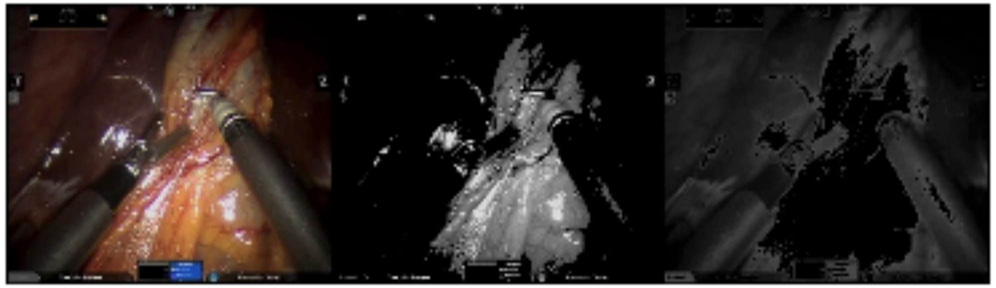
- 1) If the dark part average is smaller than **32 (thresh_low)** and the bright part average is greater than 64, the dark part will be used to measure the noise level; if the bright part average is smaller than **64,** the image is an almost black image and is not currently considered in this paper
- 2) If the dark part is recognised as the noise part, the bright part will be further divided into 2 sub-images using Otsu method. The averages and derivatives of the relevant dark and bright parts (**aveD, detD** and **aveB, detB**) and the maximum of the dark region, **maxD**, are recorded as respectively
- 3) If the initial divided dark part has averages larger than 32, this dark part is further divided until the noise part with mean value smaller than 32 is separated, the average of noise part is noted as **aveN**.
- 4) After that, the rest of the image will be threshold (Ostu) into bright and dark parts. The average, variance, maximum, **aveD, detD, maxD** and **aveB, detB** will be calculated accordingly.

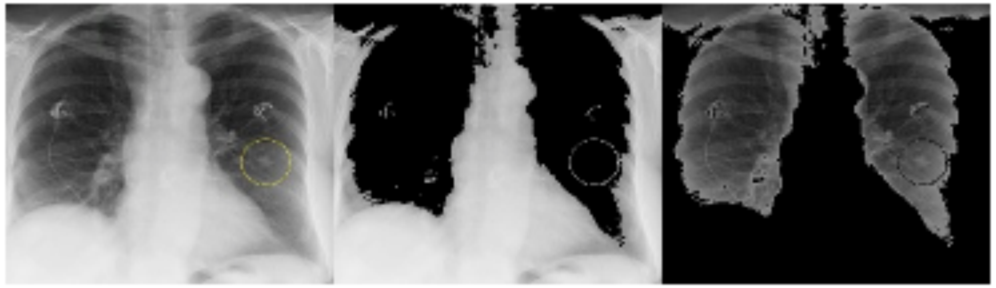
Method

The Proposed Algorithm (cont.)

- Averages and derivatives of of separated dark and bright parts are used to determine the **shape of curve** applying to the input images.

Ostu thresholding:





Method

Design of the Curve

- After applying the curves, pixels in the dark parts should have smaller values than pixels in the bright parts
- Logarithm curves $g(x)=N_i+N_i \ln(x/N_i)$ is applied to pixels larger than N_i to improve the perceptive linearity of the relevant dark region
- Near saturation region is suppressed using sinuous function to reduce the area of near saturated region

Method

Intensity Mapping Function

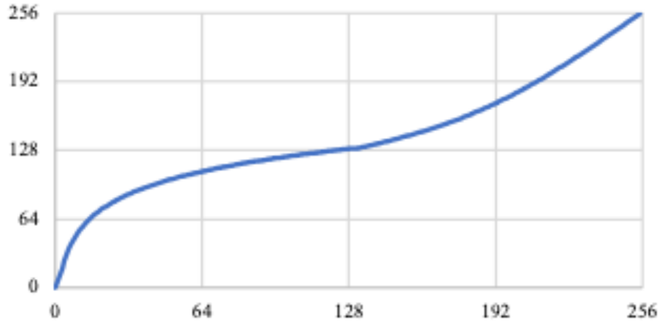
- The resulting mapping function f(x):

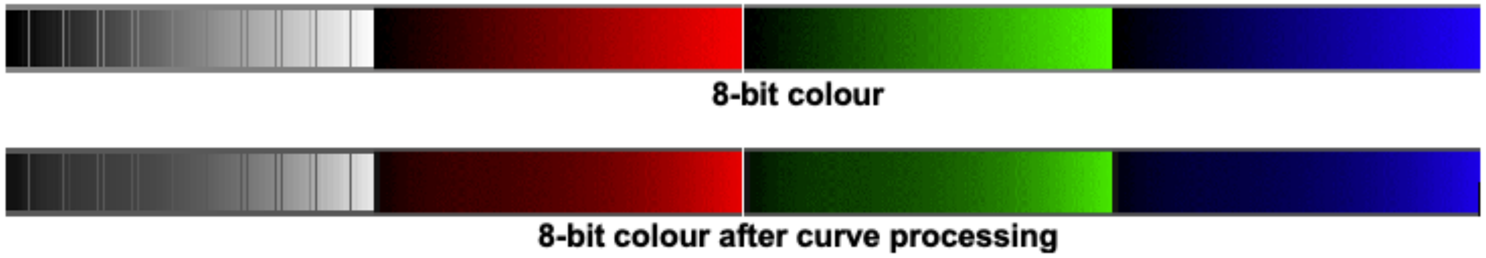
$$
f(x)=\begin{cases} (r_2-1)x+N_1 & x \text{ in } [0, N_1] \\ r_2\left(N_1+N_1 \ln\left(\frac{x}{N_1}\right)\right) & x \text{ in } (N_1, N_2] \\ r_3x+b_3-\left(A\sin\left(\frac{2\pi}{T}(x-N_2)\right)\right) & x \text{ in } (N_2, 255] \end{cases}
$$

Method

Curve

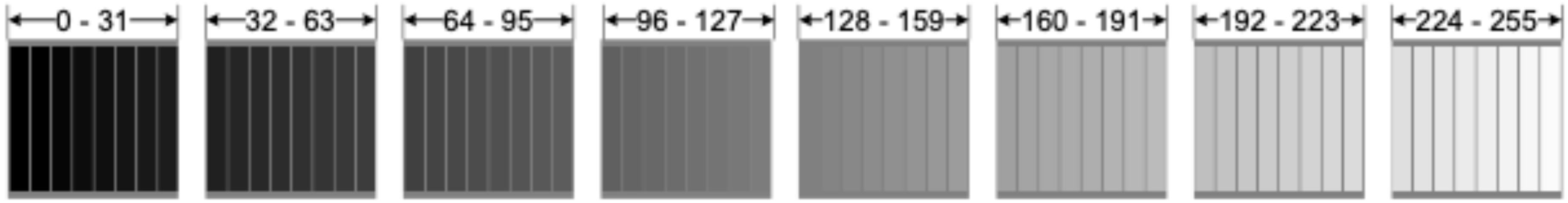
- When $ave_N = 5$, $ave_D + det_D = 130$ and the maximum value of dark region, $OutMatV_2$, is set to 130
- Curve and histogram equalization applied to 8-bit colours of gray (x, x, x), red (x, 0, 0), green (0, x, 0) and blue (0, 0, x) in order of (R, G, B), where x = [0, 255]





Design of the algorithm

- The design of the intensity mapping function and the threshold selection is based on the non-linear perception of eyes in brightness and colour to the input pixel values.
- As the 8-bit gray scale colour bar, the perception of intensity change vary in each group.
- Eyes are more sensitive to the colour difference in the mid-dark range (32 – 224) but not in the near black (0 – 32) and near saturated (224 – 255) range.



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Results

Image Enhancement Evaluation

- Image enhancement algorithms tend to be qualitative & ad hoc and they are application-dependent
- There are no theoretical guidelines in approaching an enhancement problem. Each enhancement problem is different and the criteria for enhancement are typically **subjective**.
- We want to increase the visual quality of an image, for example, but each viewer typically has a different quality norm in their mind or in their eyes. Each of us most probably will have a different preference when we are presented with processed versions of an image and we are asked to find which one has the best quality.

Image Enhancement Evaluation (cont.)

- This criteria might even be too complex to convert them to useful objective criteria. Because of that, the enhancement algorithms are qualitative and ad hoc. They kind of make sense and in most cases they work well, but they're also **application-dependent**. A different transformation of intensities might be performed if a user is to evaluate the image, or if this image is input to an object detection or an object tracking or a classification system.
- The evaluation of the effectiveness of the enhancement algorithm should also be application dependent. Again, if the enhanced image is intended for a human viewer, the criteria for evaluating its **effectiveness** should differ.

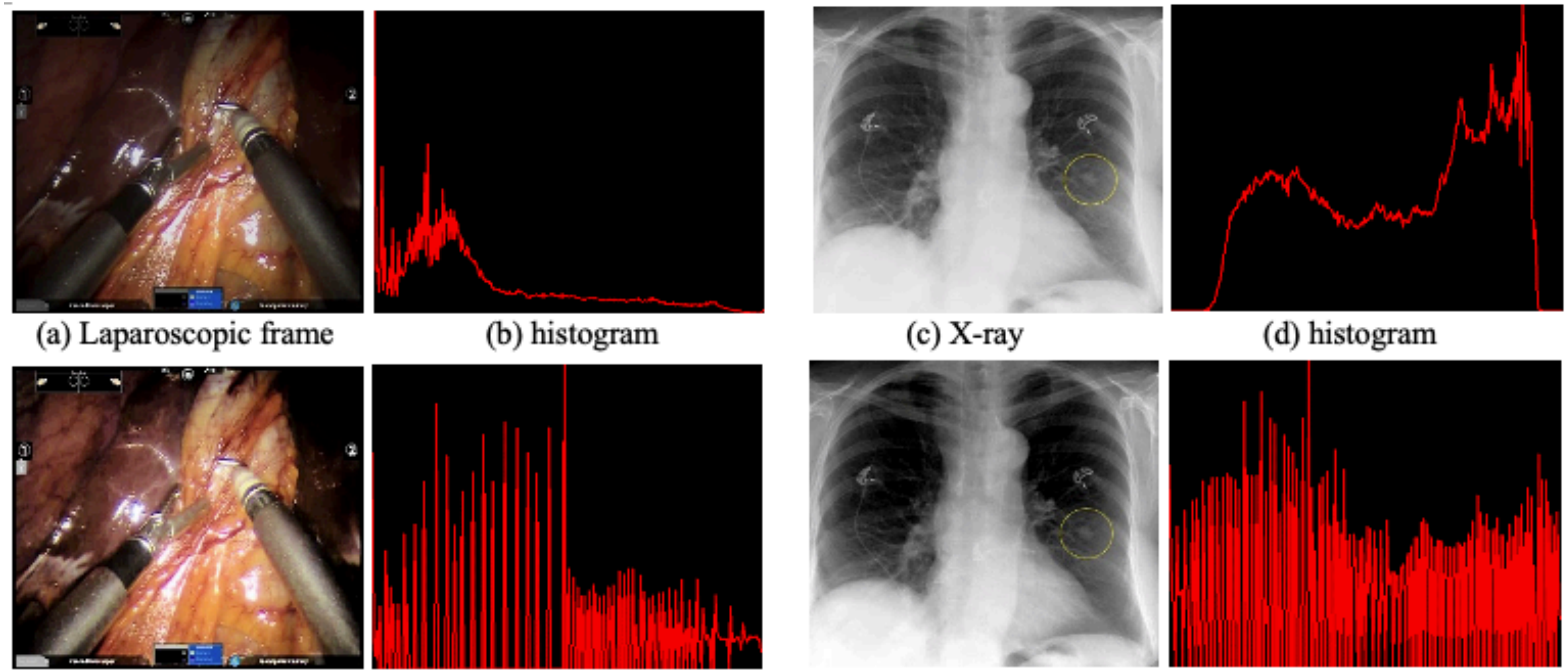
Results

Evaluation Criteria

- Amount of details revealed before / after the application
- The colour consistency and truthfulness before and after the application
- Amount of noise, alien boundaries introduced through the application of the algorithm
- Perceived change in brightness

Results

Experimental results



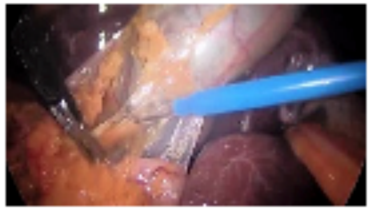
(a) Laparoscopic frame (b) histogram (c) X-ray (d) histogram

(e) processed (a) (f) histogram (g) processed (c) (h) histogram

Fei, R., Weng, Y., Zhang, Y., & Lund, J. (2021). Curve based Fast Detail Enhancement for Biomedical Images.

Results

Experimental results (cont.)

Original images	Global Histogram Equalization	Processed results
		
		
		

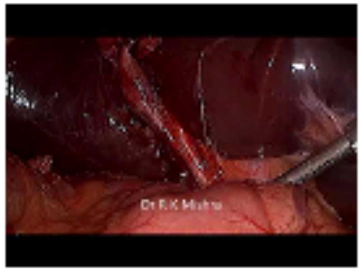
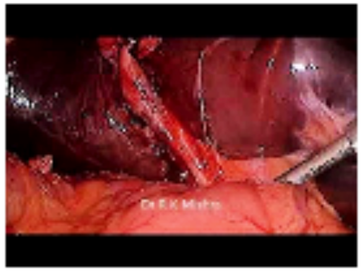
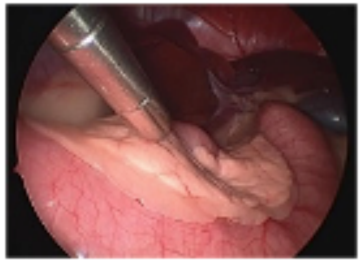
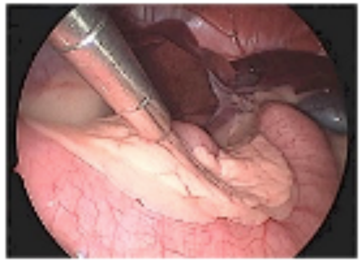
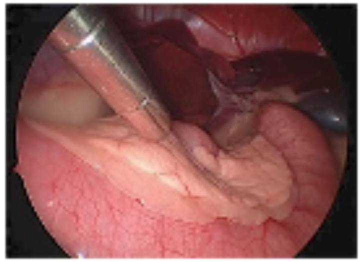
Results

Experimental results (cont.)

Original images	Global Histogram Equalization	Processed results
		
		
		

Results

Experimental results (cont.)

Original images	Global Histogram Equalization	Processed results
		
		
		

Results

Experimental results (cont.)

Original images	Global Histogram Equalization	Processed results
		
		
		

Method

Significance of the Proposed Algorithm

- After intensity mapping, global histogram equalization will have wider range of input images with different intensity distributions. i.e. high contrast laparoscopic surgical frames with have peaks in dark and/or bright regions or X-ray images with pixels distributed in mid-range.
- Apply the algorithm to a high contrast laparoscopic image, the intensity of dark region will be increased to **reveal more details** and the amplification of brightness part is suppressed without saturation.
- Apply the same strategy to X-ray image, dark and bright pixels from the input will be more evenly distributed to obtain **better eye perceived contrast**.

Method

Significance of the Proposed Algorithm (cont.)

- When applied to high contrast laparoscopic surgical frames, details including blood vessels and tissue patterns are better presented at the same time maintained the colour perception.
- Results of the algorithm applying to X-ray images are similar to results of GHE with less introduced noise level.
- The algorithm is **real-time capable for HD, 60fps, 1080*1920 video frames** with the processing speed approx.. 8ms per frame, profiled through 4-core, 2.8GHz CPU. For similar size X-ray images, the speed is around **3ms per image** as only 1 channel is processed and no colour space conversion is required.

Summary

- Image Enhancement
- Intensity Transformations
- Histogram Processing
- Global Histogram Equalization
- Local Histogram Equalization
- Adaptive Histogram Equalization
- *Curve based fast detail enhancement for biomedical images*

Where to go next?

- Conduct quantitative comparisons (PSNR, SSIM, MAE)
- Compare our method with other conventional image enhancement methods

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Thanks for listening !