CENG 462 TERM PROJECT

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Report on Contrast Limited Adaptive Histogram Equalization (CLAHE) by Karel Zuiderveld

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1. Introduction

This report aims to present an overview of Karel Zuiderveld's research paper titled "Contrast Limited Adaptive Histogram Equalization". This research presents a method used to improve digital image contrast while maintaining local details. Contrast Limited Adaptive Histogram Equalization (CLAHE) is a technique that overcomes the issue of traditional histogram equalization approaches that may cause artifacts and more noise, especially in low contrast areas.

2. Paper Summary

In the paper, Zuiderveld addresses the problem of contrast enhancement in digital images by proposing the CLAHE technique. The key objective is to adaptively equalize the histogram of image tiles while limiting the amplification of contrast to avoid introducing artifacts. The method is to divide the image into few tiles and adjust the contrast of each tile separately. CLAHE guarantees that the final image stays natural while enhancing detail visibility through shrinking the area where contrast is adjusted.

3. Methodology

The methodology used to develop CLAHE involves several steps:

- Tile Division: The input image is divided into small tiles, typically of size 8x8 pixels.
- Histogram Equalization: The histogram of each tile is computed and equalized using standard histogram equalization techniques.
- Clipping: To limit the amplification of contrast, the histogram is clipped at a specified threshold, preventing excessive enhancement of pixel values.
- CDF Interpolation: Bilinear interpolation is used to blend the cumulative distribution functions (CDFs) of neighboring tiles, ensuring smooth transitions between adjacent regions.
- Mapping: Finally, the pixel values of the input image are mapped to the enhanced values obtained from the equalized histograms.

4. Significance and Applications

CLAHE has a significant effect on image processing, especially for applications in satellite imagery, surveillance, and medical imaging. CLAHE enhances the visual quality of digital images by conserving local details while increasing contrast, which helps human observers' interpretation and analysis of the images. CLAHE, for instance, can improve the visibility of specific details in MRI or X-ray pictures, which helps with medical condition detection and treatment.

5. Code Implementation

```
pkg load image;

% function to clipping the histogram
function clipped_hist = clip_histogram(hist, clip_limit)
  excess = sum(max(hist - clip_limit, 0)); % calculate the excess pixels
  clipped_hist = min(hist, clip_limit);   % clip the histogram
  redistribute = floor(excess / length(hist)); % redistribute excess pixels
  clipped_hist += redistribute;
end

% CLAHE function definition
function result = clahe(image, clip_limit = 40, tile_grid_size = [8, 8])
  [height, width] = size(image); % get dimensions of image
  tile_height = floor(height / tile_grid_size(1)); % Calculate the dimensions
  tile_width = floor(width / tile_grid_size(2));  %  of the tiles

  % store the new image and create the tile map
  result = zeros(size(image));
  tile_map = zeros([tile_grid_size, 256]);

  % calculate the histograms and CDFs
  for i = 0:tile_grid_size(1)-1
    for j = 0:tile_grid_size(2)-1
      y1 = i * tile_height + 1;
      y2 = (i + 1) * tile_height;
      x1 = j * tile_width + 1;
      x2 = (j + 1) * tile_width;

      % Check if tiles are within boundaries
      if (y2 > height)
        y2 = height;
```

```
    end
    if (x2 > width)
      x2 = width;
    end

    tile = image(y1:y2, x1:x2);

    % clip the histogram
    hist = imhist(tile(:), 256);
    hist_clipped = clip_histogram(hist, clip_limit);

    % calculate the CDF
    cdf = cumsum(hist_clipped);
    cdf = (cdf - min(cdf)) * 255 / (max(cdf) - min(cdf));
    cdf = round(cdf);

    % store the CDF in the tile map
    tile_map(i+1, j+1, :) = cdf;
  end
end

% blending tiles with bilinear interpolation
for y = 1:height
  for x = 1:width
    i = floor((y - 1) / tile_height);
    j = floor((x - 1) / tile_width);

    % check if tiles are within boundaries
    if i >= tile_grid_size(1) - 1
      i = tile_grid_size(1) - 2;
    end
    if j >= tile_grid_size(2) - 1
```

```
      j = tile_grid_size(2) - 2;
    end

    % find position within tile
    y_rel = (y - i * tile_height) / tile_height;
    x_rel = (x - j * tile_width) / tile_width;

    % CDF interpolation
    cdf = (1 - y_rel) * (1 - x_rel) * squeeze(tile_map(i+1, j+1, :)) + ...
       (1 - y_rel) * x_rel * squeeze(tile_map(i+1, j+2, :)) + ...
       y_rel * (1 - x_rel) * squeeze(tile_map(i+2, j+1, :)) + ...
       y_rel * x_rel * squeeze(tile_map(i+2, j+2, :));

    % map the pixel value using the interpolated CDF
    result(y, x) = cdf(image(y, x) + 1);
   end
  end

  result = uint8(result); % convert to uint8
end

% load the image
image = imread('xray.png');
if size(image, 3) == 3
  image = rgb2gray(image); % convert to greyscale if in RGB
end

% call CLAHE with (image, clip_limit, [tile, tile] default = (image, 40, 8x8)
clahe_image = clahe(image, 50, [10 ,10]); % but 50 and 10,10 worked better here

% display the results
figure;
```

```
subplot(1, 2, 1);

imshow(image);

title('Original X-ray Image');


subplot(1, 2, 2);

imshow(clahe_image);

title('CLAHE Enhanced X-ray Image');
```

Note that there exists an image named xray.png within the same folder as this script.

6. Explanation of Implemented Technique

The method used in the implementation follows the paper's methodology. The histogram of each tile in the divided image is equalized using conventional histogram equalization methods. After that, the histogram is clipped to reduce the contrast amplification, and bilinear interpolation is used to combine the CDFs of nearby tiles. Lastly, the enhanced values derived from the equalized histograms are translated to the input image's pixel values.

7. Computational Process

The computational process involved in applying CLAHE to an image includes:

- Dividing the image into tiles and computing the histogram of each tile.
- Equalizing the histograms and clipping them to limit contrast amplification.
- Interpolating the CDFs of neighboring tiles using bilinear interpolation.
- Mapping the pixel values of the input image to the enhanced values obtained from the equalized histograms.

8. Results

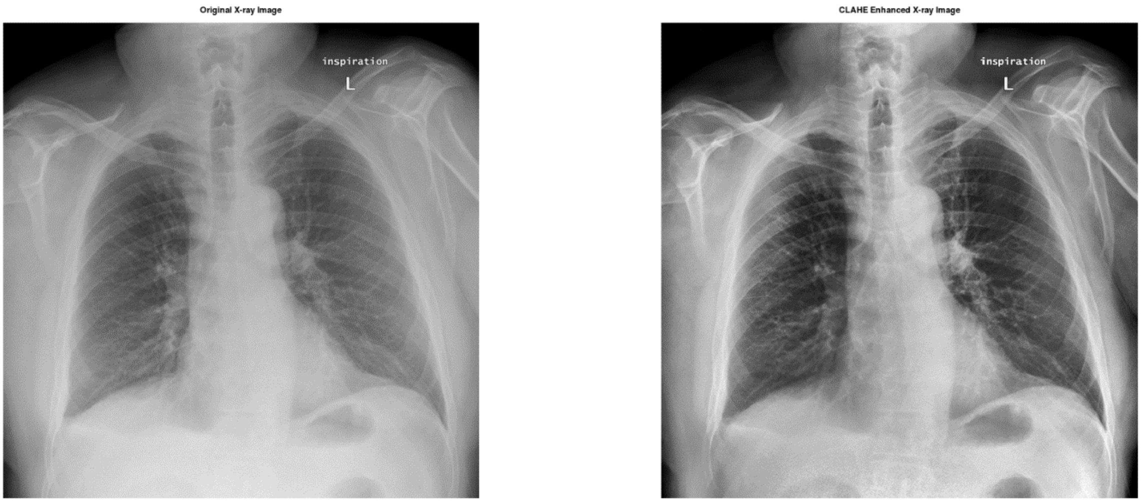

Figure 1. Original Image vs Output image (clip_limit 40, tiles 8x8)

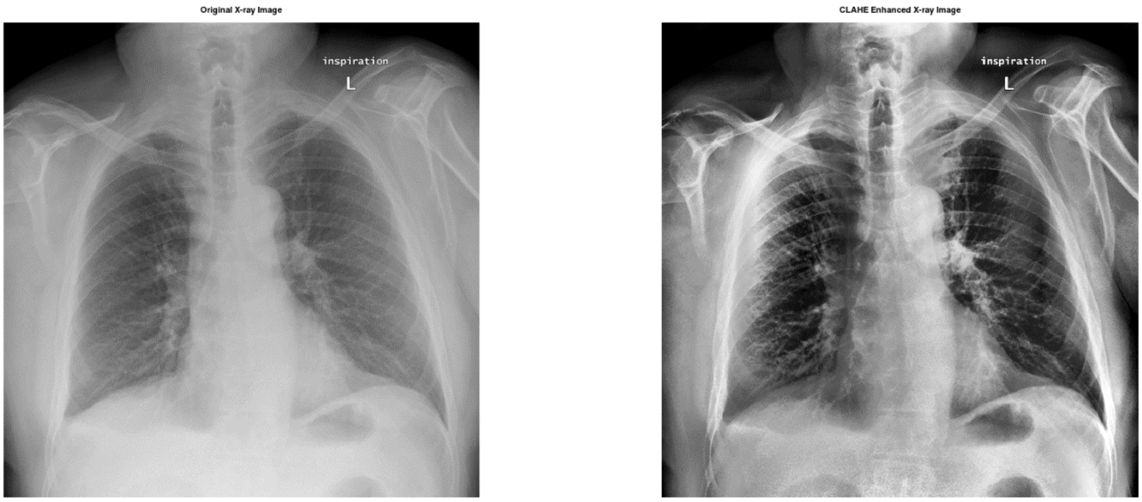

Figure 2. Original Image vs. Output Image (clip_limit 50, tiles 10x10)

9. Conclusion

In conclusion, the CLAHE technique proposed by Karel Zuiderveld offers an effective solution for contrast enhancement in digital images. By adaptively equalizing the histogram of image tiles while limiting contrast amplification, CLAHE preserves local details and improves the visual quality of images. Its importance in the field of image processing is highlighted by its many different uses.

10. References

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