Edge Detection technique based on HDR image quality assessment

Dingxian Wang*
University of California, Davis, CA 95616, USA
Corresponding Author’s Email: wdxiop@yahoo.co

Abstract. Image edge detection is one of the major study aspects in current computer image processing field. The quality of the input images is uneven, some have large fuzzy areas, some are underexposed, and the edges of objects in the images are difficult to detect, and the application scenarios of image edge detection are limited. In the view of the above problems, this paper has proposed that by applying High Dynamic Range (HDR) image quality assessment technology, combining multiple images with different exposures into one HDR image with detailed edge information, this technology effectively solved problem of low edge information richness, improved the effectiveness of edge detection algorithms, and contributed to the development of edge detection technology.

1. Introduction
Edge detection is a significant step for computer vision and image processing. Many different image processing fields such as image encryption system [1] and blood vessel detection in medical image analysis field [2] require edge detectors as a major activity to find information in images for further processing. Although a huge amount of work has been done in this aspect, edge detection techniques still have space for more contributions in the future.

The purpose of edge detection is to find pixels between items in an image, the edges, and hence reveal the information carried in the image. Since edge detection was first introduced, many detectors were proposed, and some of the methods are still being improved and used today, like Sobel operator [3], Robert operator [4] and Canny operator [5]. These edge detection techniques are effective algorithms to extract edges from images by finding sudden changes in the intensities for each pixel, see Fig. 1. In recent years, many Deep Learning (DL) based edge detection approaches, such as DeepEdge [6], BDCN [10] and HED [7], have been proposed. These methods are able to predict edges in input images with better performance than the common classic edge detectors since most of them are based on the success application of Convolutional Neural Networks (CNN) with large sets of images for training. There are many effective edge detectors, and each has its own characteristics and limitations.
The performance of edge detections is evaluated subjectively by visual observation or objectively by quantitative measurements given the true information about objectives in the image [8]. Techniques required edge detection need more precise edges to perform better. However, the performance of edge detection algorithms is also restricted by the quality of the image. Since many images need to be processed are not thoroughly picked, pre-processed or taken by ideal equipment, problems like motion blur and wrong exposure can be raised and make the edges vague or lose edge information. Proper image pre-processing is helpful in these occasions. High Dynamic Range (HDR) image is an image processing technique used in photography, display devices and other fields. This technique aims to acquire higher dynamic range in a single image, the most common method is to combine several Low Dynamic Range (LDR) images with different exposures [9], as shown in Fig. 2. This process usually can make the image more visually appealing and save more information in the image as details from multiple exposures are kept on the final image.

In this work, we propose to use the HDR technique to pre-process images to be used in edge detection. After an image is produced as a high quality HDR image, enriched details in the image make edges between objects or object and background clearer, which can solve the problem of loss of edge information and help the edge detectors have better performance in further image processing.

2. Materials and Methods
This paper uses HDR image quality assessment technology to pre-process images and edge detection techniques to further process the images. The edge detection techniques used in experiment include Canny detector, Sobel operator, Robert’s cross operator and Prewitt operator. The process is shown in Fig. 3.
Figure 3. Process of the introduced technique

2.1. HDR Image Quality Assessment Technique

The HDR image process technique we chose is exposure fusion [9], a popular image fusion method which has been used in computer graphics and photography. This technique can compute a desired picture based on a series of multi-exposure images by selecting appropriate pixels from each input image with a set of quality measurements.

To compute the quality of each pixel in input images, three measures are used to generate weight maps for images to guide the fusion process: contrast, saturation, and well-exposedness. The contrast measure is the absolute value of the Laplacian filter applied on greyscale versions of the input images [11]. The saturation measure is the standard deviation of RGB channel values in pixels. The well-exposedness measure is computed with intensities of each pixel. To find intensities of pixels that are not underexposed or overexposed, a Gaussian curve is applied:

\[
\exp \left( -\frac{(i-0.5)^2}{2\sigma^2} \right). \quad (1)
\]

Equation (1) is applied to each color channel, where \( i \) is the intensity, the multiply of all the results yields the well-exposedness measure.

The weight of each pixel is computed by (2), where \( W \) is the weight, \( C \), \( S \) and \( E \) are contrast, saturation, and well-exposedness, with corresponding exponents \( w_C \), \( w_S \) and \( w_E \).

\[
W = C^{w_C} \times S^{w_S} \times E^{w_E} \quad (2)
\]

With weight maps of the pixels of input image sequence, the normalized weight of each pixel is computed. The result can be acquired from sum of weights in \( N \) images, as shown in (3), where \( W_i \) is weight from image \( i \) in the input sequence.

\[
\bar{W} = \left[ \sum_{i=1}^{N} W_i \right]^{-1} W \quad (3)
\]

And the pixel at result image \( R \) can be created through (4), with \( P \) as the relative pixel from the input images.

\[
R = \sum_{i=1}^{N} \bar{W}_i P_i \quad (4)
\]
In order to obtain clear edges in the result image, the input images are also decomposed into a Laplacian pyramid, and the fusion result are computed with pyramid from (5) where the Gaussian pyramid and Laplacian pyramid decomposition of level \(j\) is defined as \(L(A)_j\) and \(G(A)_j\) in picture A.

\[
L(R)_j = \sum_{i=1}^{N} G(W)_i L(I)_i (5)
\]

### 2.2. Edge Detection Techniques

Edge detection algorithm use greyscale images as input and take the first and second derivative of the image to calculate intensity of the pixels. The edges in images are detected by looking for sudden change in intensity, which is achieved by applying kernels on pixel grid to calculate gradient magnitude. There are many edge detection methods, each has its own advantages based on the algorithm used. In this work, we choose to perform four common optimal edge detectors: Canny, Sobel, Robert, and Prewitt.

#### 2.2.1. Sobel Operator

Sobel operator [12] consists of two 3×3 kernels as shown in Fig. 4.

![Sobel edge detector](image)

These kernels are applied separately to the image, to generate the measurements of gradient component in two orientations, vertically and horizontally. The result can be obtained by combining the gradients from results of both orientations as in (6).

\[
|G| = \sqrt{Gx^2 + Gy^2} \quad (6)
\]

Equation (7) is also used as a simplified method.

\[
|G| = Gx + Gy \quad (7)
\]

#### 2.2.2. Robert’s cross Operator

The Robert Cross operator [13] is a simple and efficient algorithm for gradient measurement of images. There are two 2×2 kernels as shown in Fig. 5.

![Robert's cross edge detector](image)

The kernels are applied on pixel grid in two orientations, and the gradient magnitude are combined with the same equations used by Sobel edge detector.

#### 2.2.3. Prewitt operator

The Prewitt operator [14] uses two 3×3 filter masks, as shown in Fig. 6, to convolve with the original image and calculate approximations of horizontal and vertical derivatives.
Similarly, after applying the two kernels on the input image, the gradient can be computed by the same approach used by the two aforementioned edge detection methods with the results.

2.2.4. Canny Edge Detection

Canny edge detection method [5] is an optimal edge detector, as it significantly improves the quality of detection by applying several steps. First, a Gaussian filter is used to reduce noise in the image. The filter kernel in (8) is of size of \((2k+1) \times (2k+1)\).

\[
H_{ij} = \frac{1}{2\pi\sigma^2} \exp \left( -\frac{(i-(k+1))^2 + (j-(k+1))^2}{2\sigma^2} \right);
\]

\[1 \leq i, j \leq (2k + 1) \quad (8)
\]

Then, the algorithm calculates the intensity gradient and applies gradient magnitude thresholding to thin out the edges in result. Finally, to find strong edges and valuable weak edges, it performs double thresholds to identify desired strong edges and non-relevant edges, and edge tracking by hysteresis to link strong edges with weak edges that are suitable to be preserved.

3. Experiment and analysis

This chapter is the part of experiments and verification of the technique discussed in this paper. We used an experimental environment as shown in table 1.

| Hardware | CPU: Intel Core i7-8750H  
GPU: NVIDIA GeForce GTX 1060  
Memory: DDR4, 16GBytes |
|----------|---------------------------------------------------------------------------------|
| Software | Operating system: Windows 10  
Python 3.9  
MATLAB R2021a  
OpenCV-Python 4.5.3 |

For the edge detection methods used in this work, we choose to use SSIM and PSNR scores [15] to measure the quality of edge detection, with hand-labeled ground truths for all four groups of data. SSIM (structural similarity) is based on three measurements between image \(x\) and \(y\): luminance\((l)\), contrast\((c)\), and structure\((s)\). The formula with weights \(a\), \(b\) and \(g\) is shown in (9).

\[
SSIM(x, y) = \left[ l(x, y)^a \cdot c(x, y)^b \cdot s(x, y)^g \right] \quad (9)
\]
The other indicator, PSNR, can be computed with (10), with MAX as the maximum of input data type and MSE as the mean-square error between the images.

\[
PSNR = 10 \log_{10} \left( \frac{MAX^2}{MSE} \right)
\]  

(10)

The following four groups of pictures, as in Fig. 7, are used in the experiments as the raw inputs. Each group contains three photos of the same content but with different exposures.

![Input images](image)

Figure 7. Input images

To comprehensively test the feasibility of the technique introduced in this paper, four edge detection methods are used in the experiment: Canny detector, Sobel detector, Robert's cross detector, and Prewitt detector. The results of our experiment are shown in Fig. 8.
Based on the experiment results above, the data is evaluated, and the comparison of the results can be seen in table 2 shown below. The two indicators, SSIM and PSNR, are computed from each image and one manually labeled ground truth for each group.

**Table 2. Experiment Results**

| Data Group | Edge detection results | SSIM  | PSNR  |
|------------|------------------------|-------|-------|
| A          | Under                  | 0.8136| 16.9012|
|            | Normal                 | 0.4602| 13.3976|
|            | Over                   | 0.5808| 13.7158|
|            | Ours(HDR)              | 0.2799| 9.8322 |
| B          | Under                  | 0.8683| 17.5686|
|            | Normal                 | 0.6673| 12.2446|
|            | Over                   | 0.0364| 5.7233 |
|            | Ours(HDR)              | 0.0191| 5.8215 |
| C          | Under                  | 0.6202| 12.5116|
|            | Normal                 | 0.6212| 13.2368|
|            | Over                   | 0.7772| 15.3321|
|            | Ours(HDR)              | 0.4401| 9.9652 |
| D          | Under                  | 0.9076| 26.1169|

| Data Group | Edge detection results | SSIM  | PSNR  |
|------------|------------------------|-------|-------|
| A          | Under                  | 0.0236| 12.2979|
|            | Normal                 | 0.0018| 7.167 |
|            | Over                   | 0.0052| 8.5084|
|            | Ours(HDR)              | 0.003 | 7.0361|
| B          | Under                  | 0.0668| 10.8329|
|            | Normal                 | 0.002 | 7.6067|
|            | Over                   | 0.0061| 4.0829|
|            | Ours(HDR)              | 0.0002| 4.0866|
| C          | Under                  | 0.0024| 7.1019|
|            | Normal                 | 0.0033| 6.7436|
|            | Over                   | 0.1791| 9.8433|
|            | Ours(HDR)              | 0.0022| 7.2371|
| D          | Under                  | 0.0075| 11.5394|
For the experimental results shown in Fig. 8, the outputs of edge detection on most HDR pictures have visually more details on objects and backgrounds than those of normal exposure images. The advantage of our technique can be observed through the results, since the HDR images contain edge information from three exposures.

In order to further test the feasibility of the technique we introduced, the evaluation data in table 2 are analyzed. The pictures pre-processed with exposure fusion do have better performance in some datasets. In some cases, the edge detection result of HDR image does not have a higher score than other images since it contains more texture information about objects and backgrounds in the image that are not labeled in the ground truth reference.

In conclusion, the subjective and objective analysis together suggest that the pre-processed HDR image can provide more useful details in edge detection.

4. Conclusion
In order to help current edge detection applications to acquire image edge information from low quality pictures, this paper introduces a technique to combine HDR image quality assessment method with edge detection. This technique can reinforce the diversity of image information by fusing details from multiple exposures, promotes the development of high-precision image information extraction based on edge detection technologies. Through a series of experiments, the effectiveness of the edge detection technique based on HDR image quality assessment introduced by this work is fully proved.

For future research work, we will be focus on image quality assessment techniques that require single image as input and reducing the complexity of the algorithms; more proactive research works will be done to achieve more efficient and effective image edge detection techniques.
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