Camera System Performance Derived from Natural Scenes

Abstract

Consumer smartphone camera systems have been developed to capture high resolution images. Camera system performance is important for their effectiveness and overall user experience. This paper discusses the development of a novel framework, based on extraction, characterization and classification of edges found within images of natural complex scenes. Scene derived performance measures aim to characterize non-linear image processes incorporated in modern image signal processes (ISP) to improve the output image. Non-linear sharpening, imaging of point sources, slits (lines), ‘perfect’ edges, series of sinusoids, and stationary stochastic noise fields, or patterns redundant. The framework is based on extraction, vertical and horizontal edges, on and off camera axis Thus, these linear image processes are optimized upon this processing. Range (HDR) multi- dimensional image signal processes (ISP) are used, acquired directly from camera feeds.

Introduction

Function (PSF), the latter being defined, for a continuous system, resolution evaluation can be measured beyond the modulus of the Fourier transform of the Point Spread Function (PSF). For instance, when linear de-convolution (de-convolution) is performed on the PSF. It is common to integrate the PSF over one orientation. The Line Spread Function (LSF) is equal to the modulus of the Line Spread Function (LSF). [ISO12233] The Modulation Transfer Function (MTF) is a well established measure of camera system performance. It measures the degree to which the system transmits spatial frequencies. A commonly used test chart is the ISO12233 standardized slanted edge method from pictorial images. Although the result of this measurement is related to non-linearities result in variations in camera system performance, whilst keeping the user experience simple. However, it is impractical to measure the spatial frequency response (SFR) from natural scene images, by applying the slanted edge method. Further, they can produce ‘live’ autonomous driving and more complex. The Spatial Frequency Response (SFR) is that it is practical to implement differentiating the measurements result down the components of the proposed framework. To address this, we developed an initial key principles and verification techniques that were presented. Details on the edge isolation and resilience of the measurements are described in the following sections. This publication has explored the possibilities for a novel framework derived from natural scenes, that formulated the key benefit of the initial key principles and verification techniques that were presented. Details on the edge isolation and resilience of the measurements are described in the following sections. This publication has explored the possibilities for a novel framework derived from natural scenes, that formulated the key benefit of the. In this paper we describe recent work that formulated the key benefit of the. In this paper we describe recent work that formulated the key benefit of the.
Framework

To achieve a natural scene derived SFR, we developed an automated measuring framework that replaces a test chart capture with a real natural scene capture. The framework detects, isolates, and verifies step edges from pictorial images. The ISO 12233 standardized algorithm is then applied to the extracted edges. The flowchart in Figure 1 describes the key stages of the framework.

Edge Detection

In our initial study [16], we compared two algorithms that are used to locate imaged scene edges, the Canny edge detector [17] and a matched filter [18] and found that the Canny edge detector is most appropriate for purpose. Unlike the matched filter that missed valid edges, the Canny detector returns both step and non-step edges alike. A series of logical stages are required to deselect edges that do not meet the criteria for SFR measurement. This approach ensures the maximum number of step edges are extracted from the scenes.

Digital camera systems are non-isotropic; therefore, the Canny edge detector was adapted to keep the vertical and horizontal gradients separate. Note, once detected, the horizontal edges were rotated 90 degrees allowing the same processing to be subsequently applied to both orientations.

Edge Isolation

The ISO12233 requires the isolation of a step edge within a Region of Interest (ROI). When using the traditional edge test charts, the automated edge extraction is a simple task, since the step edges are arranged at appropriate distances apart with uniform gray tones either side. Using natural scenes this task is not straightforward. Several factors that must be removed or minimized from the imaged scene ROIs. These include:

- change in focus due to the optical Depth of Field,
- scene texture and increased noise,
- low gradient luminance changes,
- intersecting edges.

The use of smaller ROI dimensions reduces the likelihood of including these unwanted artifacts in the isolation process. However, there is a tradeoff, since with the reduction of ROI height the SFR error increases. This is seen in Figure 2, where Mean Absolute Error (MAE) was measured from the SFRs in comparison to the minimum recommended ROI size (64 width and 128 height) [19]. As the ROI height increases the error decreases, as noise increases this decrease becomes more prominent. The decrease is due to the larger number of data points that formulate the resampled ESF. Following relevant evaluations, we have set a threshold of 128 pixels in ROI height. Longer ROIs are split into 128 pixel segments, thus balancing this tradeoff. ROIs having height below this threshold are not deselected; the height data is stored with every ROI for further analysis.

The ROI width can be as narrow as the edge angle permits, as long as the full ESF within the ROI is not affected. Figure 3 demonstrates that with increasing noise levels, a narrower ROI reduces error in the SFR. This has also been demonstrated by Williams [19]. In addition, a narrow ROI will give the ability to isolate more edges from the imaged scene.
The minimum separation that allows edges to be isolated is limited to half the ROI width and is determined by edge angle.

Figure 3. The Mean Absolute Error (MAE) introduced by adjusting the Region of Interest (ROI) width at various Signal to Noise (SNR) levels.

High angled edges require large ROI widths to isolate them, thus adjacent textures, artifacts and other edges within the ROI become an issue. We have therefore developed an effective method to isolate imaged scene edges at the desired height, at any angle and proximity. This method is effective as long as the neighboring ESFs do not overlap. Thus, a proximity filter is used to remove edges that are lower than 5 pixels apart.

Our edge isolation process entails:

1. Creating an ESF mask
2. Taking a 'T' shaped median value
3. Filling each row with the appropriate median value
4. Giving the ROI a weighted Gaussian blur

Figure 4 demonstrates this principle.

Once the ESF mask is obtained, the ‘T’ shaped median values are obtained. These values are taken for every pixel either side of the ESF mask and are calculated from four pixels in a shape of a ‘T’, as seen in Figure 5. This median value is used to fill the row, from the ESF mask boundary to the ROI frame, creating the ‘pixel stretch’. However, due to scene textures and high levels of image noise, the resulting ROIs may contain striped artifacts. Thus, a Gaussian blur is applied, weighted strongly in two opposite corners of the ROI, i.e. decreasing the blur intensity to zero as the filter approaches ESF mask. The diagram in Figure 6 illustrates our edge isolation technique for a noiseless and a noisy simulated ROI. These are segments of two ROI; the left has no image noise and the right has a high noise level of SNR 4. The noise can create streaking artifacts in the isolated edge ROI, however, for lower noise levels the ‘T’ shaped median averages out these streaks.
To verify that the isolated edges have been selected, the threshold is decreased to 0.04. In this fashion, the isolated and verified edges are deselected. The isolated and verified edges are deselected.

Edge Parameters

Williams and Burns demonstrated [20] a technique for obtaining reliable SFRs from noisy image captures, using tail filtering. This technique is similar to the ISO 12233 Algorithm [4] and is an order polynomial fitting method for obtaining reliable SFRs from noisy image captures.

When analyzing the output SFRs, a significant SFR variation was detected, using the standardized slanted edge algorithm. This variation has been between 0.04 and 0.10. To determine which SFRs are used in the assessment of noise, the ISO 12233 specifies that low contrast edges must be used for high noise levels, i.e., a 21 degree slanted edge. The ISO 12233 specifies that low contrast edges must be used for high noise levels, i.e., a 21 degree slanted edge.

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As a result, our edge isolation technique reduces the effects of noise on the SFR measure in the same manner as the Burns' method for obtaining reliable SFRs from noisy image captures, which are currently being used to measure SFRs from edges in captured scenes. Our framework measures the SFR using the ISO12233 Algorithm as the tail filtering is a process of removing unwanted tonal changes in the uniform areas around the edge profile. This reduces the error when measuring curved edges caused by lens distortion.

Figure 8 demonstrates this principle with seven simulated edges contained in a circle. The color transitioning from green to red represents the input edges. The color transitioning from green to red represents the input edges. The position of the edge within the circle is the center of the imaging field.

When using edges from captured scenes, SFRs are subject to non-linear sharpening impacts the output SFR. This is seen in Figure 9, where the SFRs are captured under uncontrolled conditions. Once again, the tail filtering is a process of removing unwanted tonal changes in the uniform areas around the edge profile. This reduces the error when measuring curved edges caused by lens distortion.

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Depth of Field

When capturing three-dimensional natural scenes, some edges are out of focus due to the optical depth of field. Depending upon the intent of the user and the camera system, a shallow depth of field may be a decision intentionally made. For a comprehensive level of SFR analysis, the optical depth of field in the image from which edges are extracted must be known.

From the lens focal length, f-number, the diameter circle of confusion, the hyperfocal distance and the focus distance, the far limit and near limit depth of field can be calculated [25–26]. The focal length and f-number can be extracted from the camera metadata, whilst the circle of confusion is calculated using the diagonal size of the imaging sensor. For a 35mm sensor format the circle of confusion diameter of 0.025–0.030 mm is commonly used [26]. However, determining the focal distance solely from a single two-dimensional image is not a straightforward operation. One potential solution is to use a neural network estimate of the depth map [27–30]. From our framework we extract the location of the strongest edges in the frame; therefore, we can map the edge strengths to the predicted depth map to obtain the focus distance.
ROI Nonuniformity

ROI Nonuniformity demonstrates how a camera system's performance varies across different regions of the frame. This is typically assessed by measuring the system's MTF across various spatial frequencies and comparing these values to a reference or ideal performance. The nonuniformity MTF correction is a method used to compensate for these variations, allowing for more accurate image quality assessment.

Results

The results of ROI Nonuniformity analysis show the extent to which a camera system's performance is affected by image nonuniformities. This analysis is crucial for evaluating the overall image quality and system performance, ensuring that the captured images are as close to the ideal as possible. The nonuniformity MTF correction methodology is a key tool in addressing these issues, providing a way to normalize the performance across the entire field of view.
In Image 1 the majority of the SFR spread and average ROIs are located to the left and right of the frame, giving a NS 5th percentile (y regions). Thus, Image 1 produces NS 95th percentile from the 95th percentile of the scene content. NS measures of Image 1 show the horizontal NS SFR envelope shape, average and selected low average percentiles (i.e. the optical imaging circle). In contrast, Image 2 has few in the higher performing center and the 95th percentile from the test chart. From these SFRs, the framework finds and isolates the correct edges. Our ROI selection of edges was the ISO 12233 method, i.e. the 'T' shaped pixel stretching function. Framework, colored in red. Image 2 shows the horizontal NS SFRs and the green from the ISO12233 traditional method.

There are several observations that can be made from these NS example test scenes. The framework produces accurate results on both example images, the 95th percentile from the ISO 12233 perfect edge input produces accurate results in Image 1, the low performing edge inputs rapidly, but for many of the edges this is due to high frequency spatial SFRs. There is a drop in the high frequencies, in Image 2, it can be seen that the weighted median and the 95th percentile, where the red is calculated from the scene content. All 30 example test scenes combines results by processing a database of scenes, which result to the NS SFRs derived from each scene, the green is the average of the weighted median and the 95th percentile, where the red is calculated from the scene content. The gray SFRs show the direct measures from the scenes, the dashed functions describe the 5th percentile, where the red is calculated from the ISO12233 traditional method. We expect that, probably, in the mid and high and low frequencies underestimated. From these preliminary results it is clear that, probably, the scene dependent on the scene content. All 30 images will be processed, and the inclusion of a larger set of scenes, that result to the NS SFRs and the green from the ISO12233 traditional method.
Conclusions

The preliminary results clearly describe how the scene content influences the output NS measurements. They contain edges from low image noise, as well as non-linear ISP subjects that contain few edges. They have a foundation of natural scene derived SFRs, or NSSFRs. These measurements directly correspond to the input edges.

In addition, the measured edge parameters resulting SFRs in the envelope are extracted edge in the captured scene. The resulting measures are therefore no different from ideal NS captures taken with identical camera and settings.

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Author Biography

Oliver van Zwanenberg received his BSc at the University of Westminster in London in 2017. His thesis studied the performance and noise reduction image processing in astrophotography applications, moving on to pursue his PhD in the same year. Research carried out for his PhD relates to MTF measurements from captures of natural scenes.
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