Entropy Based Measure of Camera Focus*

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Abstract

A new measure for assessing camera focusing via recorded image is presented in this paper. The proposed measure bases on calculating entropy in image frequency domain, and we call it frequency domain entropy or FDE. First an intuitive explanation of measure is presented, and next tests for some classical properties that such measure should meet are conducted and commented.

1 Introduction

The camera focusing plays a large role in most computer vision applications, regardless of wether the inspection is done manually or automatically. The extent to which an image is focused, can be viewed as a level of detail that it presents (i.e. we can be interested in some details on the photographed object or the object itself). Approaches to automatic focusing can be divided in to active and passive systems. Active systems are based on emitting a sound wave or an infrared signal in order to estimate the distance of an object and thus calculate the appropriate lens position, where as in passive systems this positioning is done by iterating lens position with respect to maximizing the sharpness of an image. The CCD consumer cameras currently available on the market usually incorporate both techniques. Active systems are fast, but restricted by distance of the object of interest. Passive systems which are computationally more costly rely on the image of the actual object and are hence not subjected to these restrictions. Passive focusing is common tool in focusing CCD cameras and comprises three major parts. The first is the region of image being focused, or the focusing window. The second part is a measure of region sharpness or the "sharpness function", and the last is the optimization algorithm which finds a global extreme of the "sharpness function". A good review of principal sharpness measures methods can be found in [1]. Sharpness functions are mainly based on evaluating gradients in some region of image [1], where as some nonconventional approaches based on frequency domain were presented in [2, 3]. In this paper we present a new simple measure of sharpness in frequency domain. Image is transformed to frequency domain by fast Fourier transform (FFT), and sharpness of image is estimated by the frequency content.

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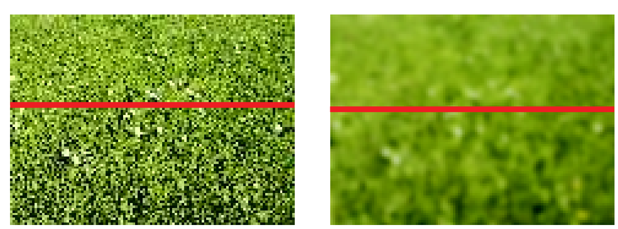
2 Frequency content of sharp and blurred image

An arbitrary image always contains low and high frequencies. If image is sharp, then the high frequency content is higher and it decreases as the image gets blurred. The latter is shown in fig. 4, where after blurring a drop in high frequencies can be seen. The same effect can be seen in fig. 1 and 2 for the two dimensional representation.



(a) (b)

Figure 1: Sharp image with selected row (a) and same image after blurring with the same row selected(b).

3 Desired properties for sharpness function

We define the desired properties of sharpness function as follows:

(i) Maximum of criteria function must correspond with best focusing position. (ii) Maximum should be

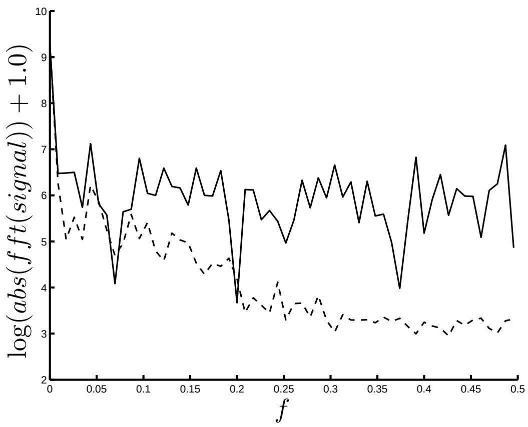


Figure 2: Frequency domain of selected row in fig. 1a (full line), and the same row in frequency domain after blurring (dashed).

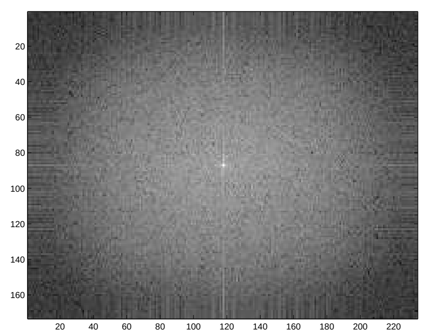


Figure 3: Absolute value of frequency domain of focused grayscale image in fig. 1a.

well expressed. (iii) The sharpness function should be strictly monotonic, or at least without expressed local minima. (iv) It should be robust with respect to different textures. (v) It should be robust to different lighting and contrast conditions.

The first and the last lemma are crucial for the function to be at least representative, where as the second and the third have more to do with the actual optimization.

4 Frequency domain based measure of sharpness

From the results in Secton 2, let us assume that as the image gets blurred, the mode at low frequencies becomes distinct due to a drop in high frequencies. Let us also assume that this happens in frequency domain obtained by a 2D FFT of a grayscale image. Because we are interested in relative amplitude of each frequency component, we calculate an absolute value of frequency spectrum and normalize it to sum to one:

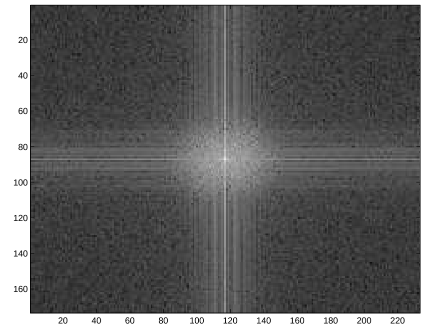


Figure 4: Absolute value of frequency domain of blurred grayscale image fig. 1b.

$$f_{norm}(i,j) = \frac{1}{\sum\limits_{(i,j)\in D} |f(i,j)|} |f(i,j)| \qquad (1)$$

Where $f(i,j)$ represents a frequency component and D denotes the frequency domain.

The obtained frequency domain can be viewed as a distribution, where each cell represents the probability that appropriate frequency is expressed. A very high or very low value of some cells implies a presence of a mode, which as we have seen forms at low frequencies when image is blurred, while approximately equal value of all cells implies a uniform distribution of frequencies and thus a sharp image.

In light of the above, we wish to obtain some measure of uniformity of f_{norm} distribution. By the first theorem in [4], we can see, that the entropy of an underlying distribution is maximal only when the distributon is uniform. This means that the entropy of distribution (eq. 1) will increase as the distribution gets close to uniform, and decrease as it get farther from uniform. In other words, provided that our assumption in the begining of this section is correct, then the maximum entropy of transformed frequency domain (eq. 1) will coincide with maximum of the image spatial sharpness. Now we can write:

$$FDE = -\sum_{(i,j)\in D} f_{norm}(i,j) \cdot \log(f_{norm}(i,j)) \qquad (2)$$

$$-\sum_{(i,j)\in D} f_{norm}(i,j) \cdot \log(f_{norm}(i,j)) \leq \mu_u \qquad (3)$$

$$\frac{-\sum\limits_{(i,j)\in D} f_{norm}(i,j) \cdot \log(f_{norm}(i,j))}{\mu_u} \leq 1 \qquad (4)$$

where μ_n is the entropy of a uniform distribution:

$$\mu_u = \sum_{(i,j)\in D} -\frac{1}{NM} \cdot \log(\frac{1}{NM}) = \log(NM) \quad (5)$$

The maximum sharpness is obtained when the left side of eq. 3 or 4 is maximized, hence our measure of sharpness is defined by eq. 2 and is called the frequency domain entropy or FDE for short.

5 Testing environment for sharpness function

In order to test the properties of FDE, we created a simple camera model, where contrast, brightness and focus can be adjusted. The model takes a focused reference image. The contrast and brightness are simulated as a linear operation on pixel values. Focus is simulated by applying Gaussian filter with selected width W which is calculated by eq. 6, where N and δ are in pixels. In eq. 6, when N equals δ, image is not blurred. The parameter δ was introduced and fixed at some value, just to avoid any possible bias of an optimization method used for focusing. In other words, the optimal value of focusing (when filter is not blurring) is not at N equals zero, but at some arbitrarily chosen δ.

$$W = 3\sigma \cdot 2 = 2 \cdot |N - \delta| \quad (6)$$

6 Assessed properties of FDE

We have sampled the values of FDE on eleven images (Appendix A) which differed in sizes as well as by content. The focus was simulated by the model from the previous section. Every image was gradually blurred from absolute sharpness to heavy blurriness, and the corresponding values of FDE were recorded. The FDE functions of all images were scaled so they could be compared, and are presented in fig. 5. As it can be seen, the FDE functions suffice the first four desired properties demanded in section 3.

In order to asses property five in section 3, the values of lighting, contrast and focus parameters in the camera model were selected randomly, and then the focus parameter was optimized by a simple Brent optimization . A Sobol quasi random generator [5] was chosen to provide three dimensional starting values for the parameters. We ran this experiment ten times for each image. The results are shown in fig. 6, and Table 1. The table shows, that filter radius in ninety nine percent of times converged to one pixel neighborhood of δ (eq. 6). In this experiment we have tested all of the properties mentioned in section five plus the optimization method, so the

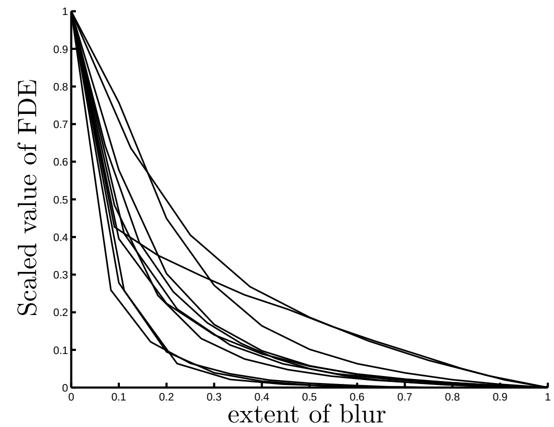


Figure 5: Comparison of shapes of FDE for different types of images.

results can be viewed as the upper bound of failure of such system. Due to the fact that robustness to lighting and contrast conditions were parameters in the experiment, it is fair to say that the assessed upper bound is also the upper bound of failure due to changes in contrast and lighting. We can thus assume that the FDE measure satisfies the last - fifth condition from section 3.

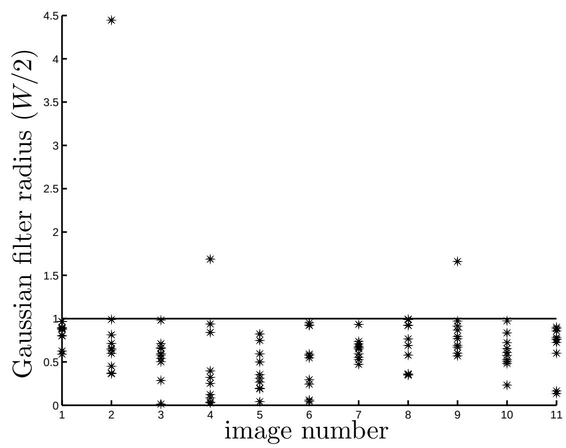


Figure 6: Convergence of Gaussian filter radius.

$\lvert N-\delta\rvert$[pixel]	$r = 0$	$r = 1$	$r > 1$
convergence	97%	2%	1%

Table 1: Convergence of Gaussian filter radius

7 Conclusion

In this paper we presented a new measure of image sharpness. The measure is based on assumption, that normalized amplitude distribution of frequency domain approaches normal distribution as an observed image (or an observed part of an image) gets in to focus. To asses the uniformity of this distribution, we calculate entropy, which increases as uniformity is approached. The entropy will probably never reach its maximum, but this does not even matter since we only want to obtain focus that results in as high entropy as possible.

The procedure is as follows. A color image is firstly transformed to gray image, and its frequency domain is calculated via 2D FFT, which due to separability [5] can be calculated via double 1D FFT. The absolute amplitudes of frequencies are calculated and normalized, so that they sum to one. Our measure of focus is an entropy of such distribution. We call it the frequency domain entropy or FDE for short.

We have tested FDE function to such extent to confidently say that it suffices the property of strict monotony, as well as maximum value at optimal focus, robustness to different textures and robustness to lighting and contrast.

Presented measure is a very intuitive but powerful tool which can be used in same manner as the existing ones e.g. [1, 2, 3]. It can be used as an edge detector as well as in shape recovery from defocused or focused images, or it could be used for depth focusing. In future research some additional testing with respect to existing methods on real cameras should be conducted.

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A Appendix

Figure 7: Images used for evaluation of FDE.