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INCREASE IN ACCURACY OF PASSIVE AUTO FOCUSING BY A NEW SHARPNESS FUNCTION

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Abstract— ***Passive auto-focusing is a key feature in digital cameras and smart-phones which uses the image sharpness function to capture focused images without any user intervention. A focused image is obtained by adjusting the distance between the lens and the image sensor using the sharpness of captured image. This paper introduces a sharpness function for achieving passive auto-focusing in digital cameras and smart-phones. It is shown that this sharpness function produces a peak when the image is in-focus and drops when the image goes out-of-focus and the amount of drop is proportional to the degree of defocus. A comparison is made between this introduced sharpness function and the commonly used sharpness functions in terms of focusing accuracy and focusing speed. A new sharpness function is presented that has a comparable accuracy to existing function while requiring fewer number of focusing iterations leading to faster focusing.***

Keywords— **Digital cameras, Passive auto-focus, sharpness function, smart-phone cameras.**

I. INTRODUCTION

In the past years, camera has been playing a more and more important role in the consumer electronics market. During the recent years, the market of camera has been obtaining an average growth of 130% per year in China. The low cost, high definition and compact camera will be the focus in consumer market. Auto-focus is a basic function in mega-pixel smart camera.

Auto focus (AF) is the key technology to control the image quality in the low cost and high quality camera market. In image quality camera focus has a profound effect and therefore plays an important role in many computer vision applications. Focus can be achieved manually or mechanically using an active or passive approach. Active auto focus methods are based on emitting a sound wave or an infrared signal in order to estimate the distance from an object, and then using the measured distance, they calculate the appropriate lens position. On the other hand, passive auto focus methods rely solely on the captured image of an object being focused, by adjusting the lens parameters with respect to some predefined criteria of camera focus.

Nowadays, most digital cameras and smart-phones possess a passive auto-focus (AF) feature that adjusts the focus motor position to attain a sharp image without any user intervention. In passive AF, a focused image is obtained by adjusting the distance between the lens and the image sensor using the sharpness of captured images. Various passive AF techniques have been discussed in the literature to replace the manual process of focusing by merely using the captured image sharpness information and not using any additional distance sensor.

The rest of this paper is arranged as follows. Section II presents an overview of some of the major conventional AF sharpness functions. Section III presents our introduced sharpness function. The behavior of this sharpness function is discussed in section IV. The comparison results are presented in section V. Finally, the conclusions are stated in Section VI.

II. AUTO-FOCUS SHARPNESS FUNCTION

Different sharpness functions have been reported in the literature. In this paper, the two sharpness functions are selected and compared to our introduced function. They are mean filter and median filter.

A. Mean filter

Mean filtering is a simple, intuitive and easy to implement method of smoothing images, i.e. the amount of intensity variation is decreasing between one pixel and the next pixel. It is often used to reduce the noise in images. The concept of mean filtering is simply to replace each pixel value in an image with the mean (`average') value of its neighbors, including itself. The unrepresentative pixel values are eliminated from their surroundings by this effect. The idea of mean filtering is usually as a convolution filter. It is based around a kernel like other convolutions, which represents the shape and size of the neighborhood to be sampled when calculating the mean. In general the mean filter acts as a low pass frequency filter which reduces the spatial intensity derivatives present in the image. This is the simplest of the mean filters.

Let Sxv represent the set of coordinates in a rectangular sub image window of size m X n, centered at point (x, y).The mean filtering process computes the average value of the depraved image g(x, y) in the area defined by Sxy.The value of the restituted image at any point (x, y) is simply the arithmetic mean computed using the pixels in the region defined by S. It is stated or interpreted in another way.

$$\hat{f}(x, y) = \frac{1}{mn} \sum_{(s,t)\in S_{xy}} g(s, t).$$

An example of mean filtering of a single 3x3 square window of values is shown below.

Unfiltered values

5	3	6
2	1	9
8	4	7

Mean value:5 + 3 + 6 + 2 + 1 + 9 + 8 + 4 + 7 =45

45 / 9 = 5

Mean value

*	*	*
*	5	*
*	*	*

Center value previously 1 is replaced by the mean value of 3x3 square window i.e. 5.

The two main problems are illustrated with mean filtering are

- The unrepresentative value of a single pixel can significantly affect the mean value of all the pixels in its neighborhood.
- The filter will interpolate new values for pixels on the edges when the filter neighborhood straddles an edge and so will blur that edge. If sharp edges are required in the output this may be a problem.

Both of these problems overcome by the median filter, which is often a better filter for reducing noise than the mean filter, but it takes longer to compute.

B. Median filer:

The median filter is normally used to reduce noise in an image somewhat like the mean filter. It often does a better job than the mean filter of preserving useful detail in the image. The impulsive noise from an image is removed as it is a non linear filter. Furthermore, it is a more powerful method than the traditional linear filtering because it preserves the sharp edges. The isolated noise can be suppressed without blurring sharp edges of the image by the effective method of median filter. Particularly, the median filter replaces a pixel by the median value of all pixels in the neighborhood:

$$y[m,n] = median\{x[i,j], (i,j) \in w\}$$

where w represents a neighborhood which is centered around location [m,n] in the image.

Median filter is a spatial filtering operation, so it uses a 2-D mask that is applied to each pixel. To centre it in a pixel apply the mask means to it, the covered pixel brightness is evaluated and determining which brightness value is the median value. Fig 1 presents the concept of spatial filtering based on a 3x3 mask window, where I is the input image and O is the output image.

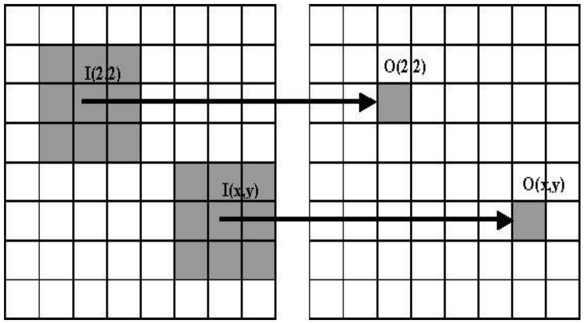

Figure-1

The median value is evaluated by first sorting all the pixel values from the surrounding neighborhood into numerical order and then replacing the pixel value being considered with the middle pixel value.

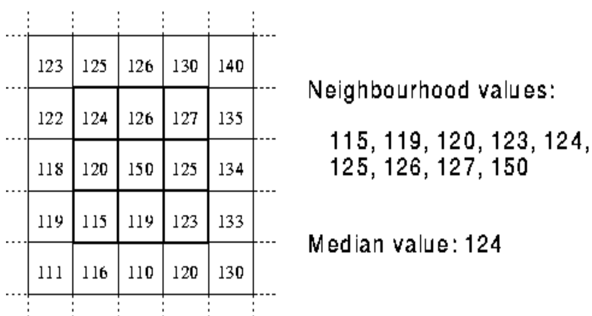

Figure-2

Fig 2 calculating the median value of a pixel neighborhood. In fig 2 the central pixel value of 150 is rather unrepresentative of the surrounding pixels and is replaced with the median value 124. A 3×3 square neighborhood is used here. Larger neighborhood pixels will produce more severe smoothing.

All smoothing techniques are effective at removing noise in smooth patches or smooth regions of an image, but adversely affect edges. At the same time it is important to preserve the edges, as reducing the noise in a signal. Edges are of critical importance to the visual appearance of images. However, its performance is not that much better than Gaussian filter for higher level of noise.

Noise image Mean filter Median filter

Figue-3

III. INTRODUCED AUTO-FOCUS SHARPNESS FUNCTION

A Gaussian smoothing is the result of smoothing an image by a Gaussian function. In graphics software this effect is widely used, typically to reduce image noise . The visual effect of this blurring technique is a smooth blur resembling that of viewing the image through a semitransparent screen, which is clearly different from the bokeh effect produced by an out of focus lens. In computer vision algorithms Gaussian smoothing is also used as a pre-processing stage in order to enhance image structures at different scales.

Mathematically, applying a Gaussian blur to an image is the same as convolving the image with a Gaussian function. This convolution is also known as a two dimensional Weierstrass transform. By disparity, convolving by a circle i.e., the bokeh effect would more accurately reproduced by a circular box blur.

Since the Fourier transform of a Gaussian function is another Gaussian, applying a Gaussian filter has the effect of reducing the image's high-frequency components; a Gaussian filter is thus a low pass filter.

The Gaussian filter is a type of image-smoothing filters that uses a Gaussian function (which also expresses the normal distribution in statistics) for calculating the transformation to apply to each pixel in the image.

In 1-D the Gaussian distribution has the form:

$$G(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}}$$

Thus the function is negative exponential one of squared parameter. The parameter divider σ plays the role of scale factor. The special name for the argument σ is standard deviation, and its square σ^2 —variance. Premultiplier in front of the exponent is selected the area below plot i.e. standard deviation to be 1. The function is defined everywhere on real axis $x \in (-\infty, \infty)$ which means it spreads endlessly to the left and to the right.

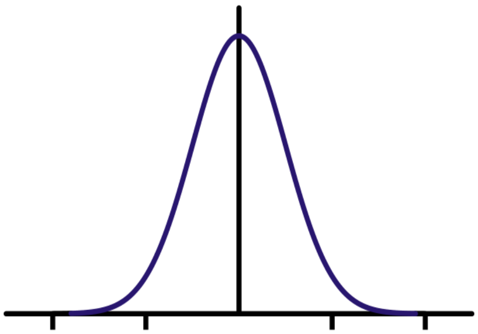

Figure-4: Gaussian distribution

Now, first point is we are working in discrete region, so at discrete points Gaussian distribution changes into the set of values. Second, we cannot work with something that spreads endlessly from left and to the right. It means Gaussian distribution is to be terminated. The question is — where? Usually in practice used the rule of 3σ that is the part of Gaussian distribution utilized is $x \in [-3\sigma, 3\sigma]$.

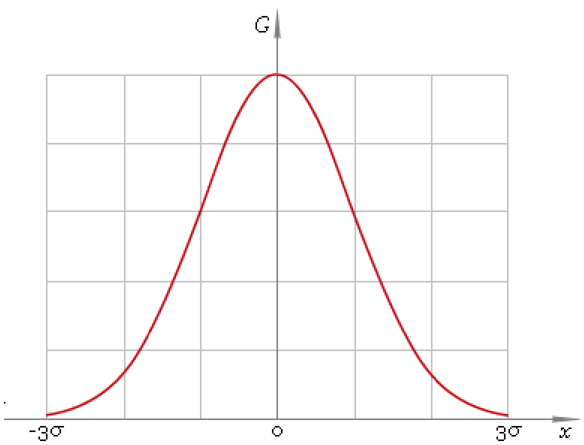

Figure-5: 1-D Gaussian distribution truncated at points ±3σ with mean 0 and σ =1

To understand that let us see how much we have trimmed. The area below terminated part is:

$$S = \frac{1}{\sigma\sqrt{2\pi}} \int_{-3\sigma}^{3\sigma} e^{-\frac{x^2}{2\sigma^2}} dx = \frac{1}{\sqrt{2\pi}} \int_{-3\sigma}^{3\sigma} e^{-\frac{1}{2}\left(\frac{x}{\sigma}\right)^2} d\frac{x}{\sigma} = \frac{1}{\sqrt{2\pi}} \int_{-3}^{3} e^{-\frac{x^2}{2}} dx$$

In 2-D, an isotropic (*i.e.* circularly symmetric) Gaussian has the form:

$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

The formula contains a number of symbols, which define how the filter will be implemented. The symbols forming part of the Gaussian Kernel formula are described in the following list:

- G(x y) – A value calculated using the Gaussian Kernel formula. This value forms part of a Kernel, representing a single element.
- π – Pi, one of the better known members of the Greek alphabet. The mathematical constant defined as 22 / 7.
- σ – The lower case version of the Greek alphabet letter Sigma. This symbol simply represents a threshold or factor value, as specified by the user.
- e – The formula references a lower case e symbol. The symbol represents Euler's number. The value of Euler's number has been defined as a mathematical constant equating to 2.71828182846.
- x, y – The variables referenced as x and y relate to pixel coordinates within an image. y Representing the vertical offset or row and xrepresents the horizontal offset or column.

This distribution is shown in Fig 6

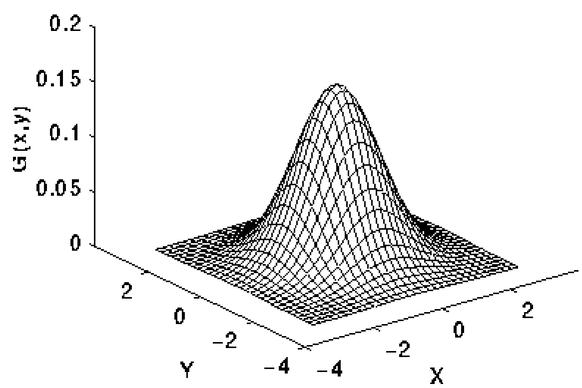

Figure-6: 2-D Gaussian distribution with mean (0, 0) and σ =1

The use this 2-D distribution as a `point-spread' function is the idea of Gaussian smoothing, and this is achieved by convolution. Before we can perform the convolution we need to produce a discrete approximation to the Gaussian function since the image is stored as a collection of discrete pixels. In theory, everywhere the Gaussian distribution is non-zero, which would require an infinitely large convolution kernel, but it is effectively zero more than about three standard deviations from the mean in practice, and so we can truncate the kernel at this point.

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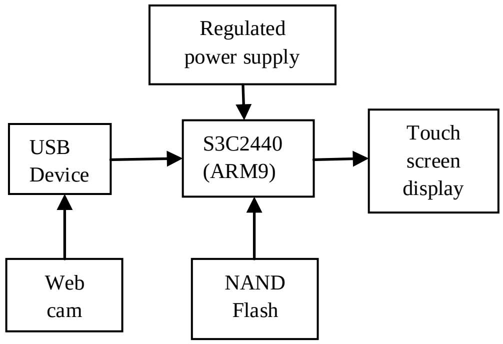


Figure-7: Experimental block diagram of increase in accuracy of passive auto focusing by a new sharpness function

IV. BEHAVIOR OF INTRODUCED SHARPNESS FUNCTION

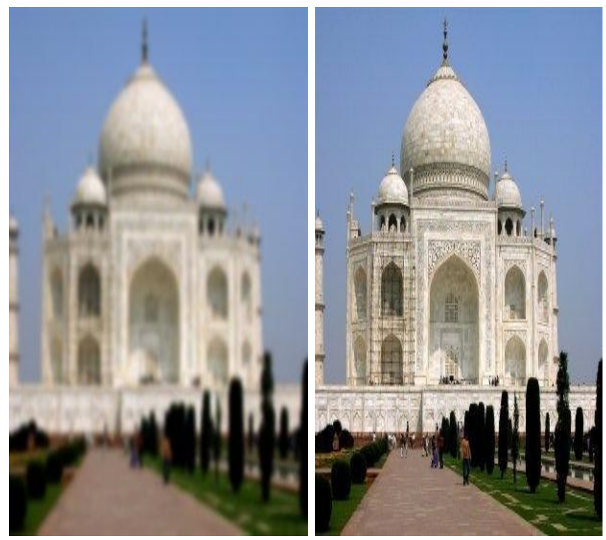
A Gaussian blur effect is typically generated by convolving an image with a kernel of Gaussian values. The Gaussian blur's separable property will divide the process into two passes and it is the best advantage to implement in practice. A one dimensional kernel is used to blur the image in only the horizontal or vertical direction in the first pass. Another one-dimensional kernel is used to blur in the remaining direction in the second pass. The Gaussian function requires fewer calculations for two-dimensional kernel to convolve within a single pass, but resulting effect is the same as separable property.

$$G(x,y)=\frac{1}{2\pi\sigma^2}e^{-\frac{x^2+y^2}{2\sigma^2}}=\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{x^2}{2\sigma^2}}\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{y^2}{2\sigma^2}}=G(x)G(y)$$

Normally at positions corresponding to the midpoints of each pixel, discretisation is typically achieved by sampling the Gaussian filter kernel at discrete points. For very small filter kernels, point sampling the Gaussian function with very few samples leads to a large error although it reduces the computational cost. In these cases, accuracy is maintained (at a slight computational cost) by integration of the Gaussian function over each pixel's area.

The sum of the values will be different from 1,when converting the Gaussian's continuous values into the discrete values needed for a kernel. This will cause a brightening or darkening of the image. To solve this, the values can be normalized by dividing each term in the kernel by the sum of all terms in the kernel.

The effect of Gaussian smoothing is to smooth an image. The degree of smoothing is determined by the standard deviation of the Gaussian. (Of course, larger convolution kernels in order to be accurately represented require larger standard deviation Gaussians,).The Gaussian filter outputs, are the `weighted average' of each pixel's neighborhood, with the average weighted more towards the value of the central pixels. A Gaussian provides gentler smoothing and preserves edges because of this weighted average. Due to its frequency response Gaussian is used as a smoothing filter and this is the principle justification for using it . Most convolution-based smoothing filters act as low pass frequency filters. This means that their effect is to remove high spatial frequency components from an image. The effect of frequency response of a convolution filter can be seen by taking the Fourier transform of the filter on different spatial frequencies.



Original image Gaussian smoothed image

Figure-8

V. IMPLEMENTATION RESULTS

A comparison is presented in this section to show the performance of the introduced sharpness function. This introduces a new sharpness function for achieving passive auto-focusing in smart-phones. The Original Image is noisy image and De-noised image using mean filter, Median filter and Gaussian filter and comparison is done among them. A new sharpness function is presented that has a comparable accuracy to existing function while requiring fewer number of focusing iterations leading to faster focusing.

The presence of high dynamic range in a sharpness function is of importance as a high dynamic range allows focusing to be achieved in fewer numbers of iterations. For example, when using Gaussian function, a higher dynamic range translates into fewer iterations of focusing control or a shorter total focusing time. Fig 3 shows the difference of the image towards seeking the peak position using the mean and median sharpness functions for a sample scène. Fig 8 shows the difference of the image using the Gaussian filter. The Gaussian filter will preserve the edges better than the mean filter and median filter.

Figure-9: Capturing the image

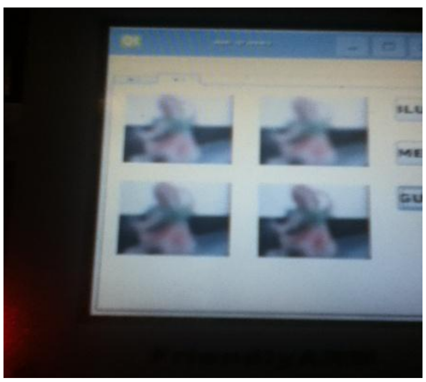


Figure-10: Applying filters to the captured image

To evaluate the performance of the sharpness function, device is tested in the laboratory environment. Fig 9 and 10 shows the four easy control options which are provided to manually operate the device. First option is to capture the image and second one is used to apply the mean function and the third option is used to apply the median function and last option is used to apply the Gaussian function. The device provides output image to the user in response to the options selected.

VI. CONCLUSION

The sharpness device has been successfully designed and tested. A new sharpness function for achieving passive auto focusing in smart-phone cameras has been introduced

in this paper. It has been shown that this function has a maximum, and is monotonically decreasing which makes it an effective function for performing passive auto-focusing. The introduced sharpness function was compared to the commonly used sharpness functions. The results obtained indicate that this new function provides comparable focusing accuracy while it demands fewer focusing iterations or achieves faster focusing.

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