A HUMAN VISUAL SYSTEM-BASED MODEL FOR BLUR/SHARPNESS PERCEPTION

Rony Ferzli and Lina J. Karam
Department of Electrical Engineering, Arizona State University, Tempe AZ 85287-5706

ABSTRACT

This work presents a Human Visual System (HVS)-based blur/sharpness perception model that can be incorporated into no-reference objective blurriness/sharpness metrics. This work is motivated by the fact that existing no-reference metrics fail in predicting the correct amount of blurriness in images with different contexts. Subjective testing is performed for a better understanding of blur perception and an HVS-based blur/sharpness perception model is derived based on the obtained results; this model can be embedded within an objective no-reference blurriness/sharpness metric to increase the correlation between metric output and perceived blurriness.

1. INTRODUCTION

Recently, there has been an increased interest in quality metrics that can predict automatically, without human intervention, the quality of the image or video stream. These metrics can be useful in various image/video processing applications, such as compression, communication, printing, display, analysis, registration, restoration and enhancement [1]. Being able to replace subjective assessment will reduce the cost considerably enabling, at the same time, real-time implementation. Objective metrics can be divided into three categories: full-reference, no-reference, and reduced-reference. In the former case, a processed image is compared to a reference such as the original image. In the second case, the metric is not relative to a reference image, but rather an absolute value is computed based on some characteristics of the given image. Quality assessment without a reference is a challenging task; distinction between image features and impairments is often ambiguous [2]. Of particular interest to this work are the no-reference blurriness/sharpness objective metrics. Blur in an image is due to the attenuation of the high spatial frequencies, which commonly occurs during filtering or visual data compression. The image blurriness metric can be also used to measure sharpness since blurriness and sharpness are inversely proportional. In this paper, we provide a testing scenario where all available no-reference blurriness/sharpness metrics fail, which motivates the need of a HVS-based model for predicting the perceived blurriness/sharpness. Subjective blur perception tests are performed and an HVS-based blur/sharpness model is derived. This abstract is organized as follows. Section 2 presents a motivation for the need of an HVS-based image blur/sharpness metric and presents the results of available no-reference sharpness metric to images having different level of blurriness and with different content. Section 3 describes the subjective tests as well as the derived HVS-based blur/sharpness perception model. A conclusion is given in Section 4.

2. OBJECTIVE NO-REFERENCE SHARPNESS METRICS

Several no-reference objective sharpness metrics were suggested throughout the literature [3-11]. These can be divided into several categories starting by pixel-based techniques and including analysis of statistical properties and correlation between pixels. Transform-based approaches are also extensively used taking advantage of the fact that sharper edges increase the high frequency components. In addition, techniques based on image gradient and Laplacian, detecting the slope of the edges in an image are presented. An overview as well as performance comparison of the mentioned metrics can be found in [12] where results were obtained for images of the same scene with different amount of gaussian blur. This work focuses on the relative blur/sharpness of images with different scenes. In this case, the available sharpness metrics [3-11] were applied to a testing set consisting of four 512x512 different images, having different content, blurred using 7x7 gaussian filters with standard deviations equal to 0.8, 1.6, 2.0 and 2.4, respectively. A snapshot of the testing set is shown in Fig. 1. Obviously, for proper operation, it is expected that the sharpness metric decreases monotonically as the amount of blurriness increases. Simulation results showed that all existing metrics will fail to predict the increase in blurriness as shown in Table 1. Note that, for each metric, the results are normalized to the maximum obtained value in the testing set. The failure of the metrics can be due to the difference in the local image characteristics including intensity, frequency, and contrast.
Table 1. Performance of different objective no-reference metrics to the testing set (Fig. 1)

<table>
<thead>
<tr>
<th>Metric*</th>
<th>0.8</th>
<th>1.6</th>
<th>2.0</th>
<th>2.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variance [3]</td>
<td>0.67</td>
<td>0.98</td>
<td>0.88</td>
<td>1.00</td>
</tr>
<tr>
<td>Auto-Correlation based [4]</td>
<td>0.99</td>
<td>1.00</td>
<td>0.59</td>
<td>0.82</td>
</tr>
<tr>
<td>Gradient [5]</td>
<td>0.73</td>
<td>0.74</td>
<td>0.59</td>
<td>1.00</td>
</tr>
<tr>
<td>Laplacien [5]</td>
<td>1.00</td>
<td>0.21</td>
<td>0.14</td>
<td>0.28</td>
</tr>
<tr>
<td>Perceptual blur [6]</td>
<td>0.30</td>
<td>0.61</td>
<td>1.00</td>
<td>0.50</td>
</tr>
<tr>
<td>Frequency threshold [7]</td>
<td>1.00</td>
<td>0.85</td>
<td>0.71</td>
<td>0.97</td>
</tr>
<tr>
<td>Kurtosis [8-9]</td>
<td>0.12</td>
<td>0.09</td>
<td>1.00</td>
<td>0.45</td>
</tr>
<tr>
<td>Histogram threshold [7]</td>
<td>0.46</td>
<td>0.82</td>
<td>1.00</td>
<td>0.71</td>
</tr>
<tr>
<td>Histogram entropy based [10]</td>
<td>0.94</td>
<td>0.99</td>
<td>0.99</td>
<td>1.00</td>
</tr>
<tr>
<td>Histogram frequency based [11]</td>
<td>0.82</td>
<td>0.94</td>
<td>1.00</td>
<td>0.97</td>
</tr>
</tbody>
</table>

*Overview of these metrics can be found in [12]

Figure 2. Probability of a correct guess given by a subject knowing the difference in blurriness variance.

The failure of the metrics can be due to the difference in the local image characteristics including intensity, frequency, and contrast. Since all metrics failed to predict the correct amount of blurriness, we conducted an initial subjective testing, which we refer to as “Subjective Test 1”, in order to check whether the difference in blurriness can or cannot be perceived by the HVS. The subjective experiment followed the ITUT-R BT.500-10 [13] and were conducted as follows:

1. Subjects were given a set of instructions before starting such as how to conduct the experiments, and what is the objective of the experiment.
2. Experiments are conducted using a 21” CRT SUN monitor.
3. From time to time, the screen is grayed to avoid the effect of persistence.

Four subjects, with no image processing experience and with normal to corrected-normal vision participated in the experiment; the subjects had to compare the two images in each of 6 combinations and state which one is more blurred. Results reveal that the majority of the subjects were able to differentiate the level of blurriness between different images, even when the blurriness amount difference is small, while none of the existing metrics did. Obtained results from subjects are summarized in Table 2. Fig. 2 shows the probability of a subject providing a correct guess, given the difference in blurriness variance levels. It can be noted that for a difference equals or greater to 1.6, the subject can surely detect which image is more blurry. In addition, out of the 24 answers, 20 were correct giving a mean of 0.8 and a variance of 0.2.
As a result, there is a need to develop a reliable HVS-based blur/sharpness metric that can predict the perceived sharpness. For this purpose, we study the behavior of the HVS when exposed to different levels of blurriness and try to derive an HVS-based blur/sharpness perception model that can be incorporated within a no-reference blur/sharpness metric.

3. PROPOSED HVS-BASED BLUR/SHARPNESS PERCEPTION MODEL

3.1. Performed Subjective Tests

A great deal of research has been done in the field of video quality analysis using algorithms which simulate the human visual system [14]. Most of these algorithms are based on the notion of “Just Noticeable Difference” (JND). By definition, the JND is the minimum amount by which a stimulus intensity must be changed in order to produce a noticeable variation in sensory experience. In other words, the required difference such that the standard observer can detect a change of intensity [15]. Weber’s law states that the contrast sensitivity is almost independent of absolute luminance levels; rather, relative changes in luminance are important. In this work, in order to study the response of the HVS to blurriness and sharpness in images, subjective experiments were performed to obtain results about blur perception and just-noticeable blurs. The conducted experiments make use of a foreground square with uniform intensity $I_F$ over a uniform background with intensity $I_B$. For a given contrast ratio, which should be greater than the JND, the subject has the ability to control the inner square by introducing blurriness. The blurriness is created using a $7 \times 7$ gaussian lowpass filter mask. Starting at a blur level of zero, the subject can increase the standard deviation of the filter at a step of 0.1. The subject also has the ability to decrease the blurriness for better control. The subject should be able to detect what we refer to as the “Just Noticeable Blurriness” (JNB). Whenever the JNB is reached, the subject presses a button, which displays another set of intensities for the foreground and, thus, a different contrast ratio. Overall, each subject is exposed to 20 different cases where the difference in contrast varies between 10 and 200. Since the JNB is not a function of the background level, but a function of the difference in intensities, thus, there is no need to compute the contrast ratio. The only requirement is that the difference in intensity must greater than the JND. Note that the displayed contrast will not increase monotonically; rather, the program will shuffle randomly the 20 cases. Also, it is worth mentioning that the absolute intensity of the background is randomly picked. At the end of the experiment, the response of the subject is stored in a file. The total number of subjects who participated in the experiments, which we referred to as “Subjective Test 2”, is 16 (12 male and 4 females) with normal and corrected-normal vision. Data is collected and used to derive an equation describing the HVS blur/sharpness perception model. The conducted subjective experiments followed the ITUT-R BT.500-10 recommendation [13] similar to “Subjective Test 1”. Fig.3 shows a snapshot of the display and interface for the conducted experiments; in reality, the square is a $128 \times 128$ located in the middle of the screen.
3.2. Derived Model

A model is derived based on the collected data from the subjective experiments described in Section 3.1. Obviously, there is a variation in the subjects’ responses and, thus, a ‘Mean Just-Noticeable Blur’ (MJNB) is computed. The MJNB is computed by collecting the gaussian blur variance, for every contrast ratio, selected by subjects as corresponding to the JNB and calculating the mean. The total number of computed MJNBs is equal to the number of cases presented to every subject which is equal to 20. The next step is to use the computed MJNBs to derive the HVS-based blur perception model; this is performed by performing a least squares curve fitting of the data [14]. The derived model is described by two regions; the first is linear while the second is exponential. The equation for the derived model is given by:

\[
MJNB = \begin{cases} 
0.42C + 1, & \text{for } 0 \leq C \leq 50 \\
0.8e^{-0.024(C-50)}, & \text{for } 51 \leq C \leq 200
\end{cases}
\]  

(1)

where 'C' is the contrast. Note that the equation follows closely the intuitive reasoning that as the contrast increases the JNB decreases.

4. CONCLUSION

Simulation results showed that none of the existing no-reference objective blurriness/sharpness metrics give satisfying results when applied to images with different scenes. A simple blur/sharpness perception model is derived taking into account the response of the HVS to blur/sharpness at different contrast levels. The proposed model, combined with a suitable objective no-reference metric, can be used as a context-independent no reference blurriness/sharpness metric as part of a control mechanism for multimedia content in portable devices such as handheld devices. For example, existing sharpness metrics can be compensated by a weighting factor that is derived from the proposed model.

5. REFERENCES