Illumination Analysis of Inactive Indoor Scenes with the Discrete Fourier Transform of Structural Distortions

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***Abstract*—Light has always played a very important role in human economic activities. Nevertheless, there are only a few popular sources of electric light. While incandescent amps have been popular in the past, they are not energy efficient. In recent years, fluorescent lamps are becoming popular as an alternative and this is especially true for schools and businesses. Probably due to these developments, there has been some significant interest in examining the consistency of the light intensity from electric lamps. While some have looked at this as a means to quickly identify the system components of fluorescent lamps, others have analyzed this to help identify the liveness of the scene. High speed video cameras can easily detect variations in the illumination levels from fluorescent lamps, but they can be quite costly to operate. Moreover, most popular security video cameras can only operate up to a maximum speed of 30 frames per second. This paper examines the use of *Structural Distortion* as an image quality measure to detect flickering on video signals from the video cameras at low frame rates. Future research is outlined at the end of the paper.**

***Index Terms*—lighting systems, image quality metrics, illumination analysis, incandescent lamps, fluorescent lamps**

I. Introduction

Humans have always depended on the Sun as a reliable source of light. Without light, there would be no life. Then when fire was discovered, the flaming torch and the fire around the camp site were probably our ancestors first use of '*artificial*' lighting. For without such early "*lamps*" most if not all human activities would cease at sundown. This is because the two main components of the human visual system, the cones and rods only work well under certain light conditions. While the cones are responsible for vision under normal light, the rods play a larger role for vision under very low light conditions. As the cone cells are not as sensitive as rod cells, they are not involved in night vision.

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Hence, fire as an artificial source of light provided Man some small degree of freedom from the blindness of the dark, and some small degree of safety from the fear of unseen prowling beasts. Nevertheless, the open fire torches eventually evolved into simple oil lamps which were usually made in the form of small open bowls with a lip or spout to hold the wick. The fuel that provided the fire and light are either animal fats, fish oils or vegetable oils (palm and olive). With the invention of electricity, electric lamps become the main source of indoor light when there is electricity supply.

For modern indoor lighting, the source of light is from electric lamps and there are only but a small number of different types [1]. One popular source is the incandescent lamp which basically consists of a metal filament that is heated to high temperatures. However, incandescent lamps are known to be inefficient as they tend to give off a tremendous amount of waste heat. The next category of light source comes in the form of an electric arc lamp. These are designed such that within the bulb itself, there is a mixture of gaseous metals and inert gases. When an electric current is applied to this lamp, light is produced as the electrons in the metal atoms dropped from a higher excited energy state to a lower one. The third popular type is the fluorescent lamp and this is especially common in commercial premises. Businesses and academic institutions find significant cost savings from using these lamps. The fluorescent lamp works by generating high-speed electrons that strike the gas particles that are trapped within the light tube. Finally, light emitting diodes (LEDs) have become more popular as a alternative source of light due to their lower power consumption and yet powerful illumination. A LED lamp is a solid-state lamp that uses light-emitting diodes (LEDs) as the source of light. Nevertheless, due to its higher initial financial outlay, most commercial premises have shied away from deploying such LED lights. Hence, when it comes to the total cost of operating business lighting for commercial sites, fluorescent lamps are still more cost-effective.

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A typical fluorescent lighting system consists of several key components, namely, a fluorescent lamp, a ballast, and finally, a starter unit. Fluorescent lamps using magnetic power line frequency ballast do not give out a steady light. Instead, they flicker at twice the supply frequency as shown in Fig. 1, resulting in fluctuations not only with light output but colour temperature as well [2].

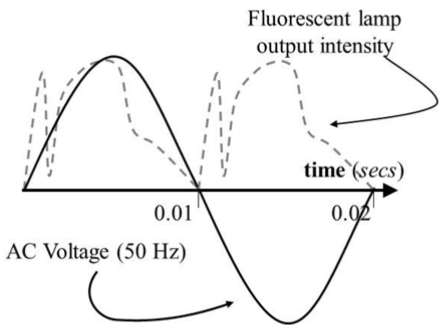


Figure 1. Effect of the AC power supply on the intensity of illumination [3].

However, the flicker is too fast for the human eye to detect. Moreover, aging fluorescent lamps can also result in inconsistent and imperfect illumination patterns, due to a dynamic instability inherent in the negative resistance of the plasma source [4].

Nevertheless, in a good fluorescent lighting system, two pulses of light are emitted for each cycle of the AC power supply - one during the positive portion of the cycle and one during the negative portion. Consequently, such variations in the illumination will affect the scene that depends on this source of illumination. Despite this, fluorescent lamps are popular as an indoor light source in many commercial sites.

The average and common video cameras can only operate up to a maximum speed of 30 frames per second. Even though high speed video cameras can easily identify variations in the scene caused by the inconsistent level of illumination from the fluorescent lamps [5] nevertheless,

- They are very costly, some priced at more than 80 times higher than the common popular ones,
- They need a very strong light source due to the high frame rate speeds.

Moreover, detection of the flickering due to fluorescent lamps may also be crucial if we want to identify the type of ballast used. A ballast is a device intended to limit the amount of current in an electric circuit [6]. Otherwise the current through the tube would increase to destructive levels due to the tube's negative resistance characteristic. The flicker index is used for measuring the perceptible light modulation. It ranges from 0 to 1, with 0 indicating the lowest possibility of flickering and 1 indicating the highest. Lamps operated with magnetic ballasts have a flicker index between 0.04-0.07 while electronic ballasts have a flicker index that is less than 0.01 [7]. Other than getting to know the type of ballast used, Lai and Tomas [8] have described a scene liveness detection invention based on the ability to detect the flicker fluctuations in the image due to the presence of fluorescent lamps.

II. Previous Work

The approach by Xia and Zhang [9] to detect a magnetic ballast in fluorescent lights basically consists of a portable electronic device to measure the amount of flickering coming from the fluorescent tube. They used this to specially identify the magnetic type of ballast that is used to drive the fluorescent lamp. We propose that as changes in the light intensity will change the overall quality of the image, image quality measures may be used to compute and identify the flickering of these images as well. After all, an image or video signal can be thought of as a sum of a perfect reference signal plus an error signal. Hence, image quality measures may be used.

Although the Mean-Sum-of-Error (MSE) is a popular and common metric to measure the quality of the video image, it has been criticized as insensitive in capturing any differences that even the human visual system can [10]. Essentially its main fault lies in that it does not correlate well with the human perception of quality. Another major criticism is in the way the MSE is computed which differs significantly in the way humans access any perceived distortion.

A related area is video segmentation where simple pixel pairs were compared to detect any quantitative change between each pair of images [11]. By comparing the corresponding pixels in the two frames, it is relatively easy to determine the number of pixels that may have changed. If the percentage of change exceeds some appropriate, preset threshold, it will then alert the user that a frame change has occurred. Due to its simplicity, it is very popular despite a large processing overhead is required and when the size of the images is large, the subsequent computation may prove to be too much.

Another approach analyses the colour histogram of the images. Pass and Zabih adopted a histogram refinement approach that uses colour coherence vectors based on spatial coherence [12]. With this, there would be significant savings in processing time and resources and this makes it very attractive. Instead of processing multiple frames, this approach will only need to process a single frame. Nevertheless, it has been pointed out that such an approach may not be sensitive to object motion. Another approach uses key frame detection in the HVC colour space [13] [pp 369]. Ha [14] explored liveness detection of human faces for biometric authentication with a machine learning approach. Within this same field of facial biometrics, *Wei Bao et al* investigated liveness detection with optical flow [15]. Shechtman, Caspi and Iran have adopted a multi-camera approach where the images from different cameras are combined together to detect any high speed motion [16]. Even though they were able to reconstruct high quality video from static, primarily outdoor scenes, this had not been without some significant trade-offs. Additional cameras as well as more complicated processing are required. In our approach, we are only adopting a single camera to capture the scene to compute the appropriate quality measure.

III. Image Quality Measure

A. Structural Distortion

Structural distortion (SD) strives to imitate the human visual system (HVS) in extracting structural information from the scene. SD was able to identify any image distortion in images [17] and is defined as,

$$SD = \frac{4\sigma_{xy}\tilde{x}\tilde{y}}{\left(\sigma_x^2+\sigma_y^2\right)\left[(\tilde{x})^2+(\tilde{y})^2\right]} \tag{1}$$

where,

$$\tilde{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \,,\quad \tilde{y} = \frac{1}{N}\sum_{i=1}^{N} y_i$$

$$\sigma_x^2 = \frac{1}{N-1}\sum_{i=1}^{N}(x_i-\tilde{x})^2 \,,\quad \sigma_y^2 = \frac{1}{N-1}\sum_{i=1}^{N}(y_i-\tilde{y})^2$$

and finally,

$$\sigma_{xy} = \frac{1}{N-1}\sum_{i=1}^{N}(x_i-\tilde{x})(y_i-\tilde{y})$$

The distortion is modeled as a combination of (i) correlation losses, (ii) mean distortion and finally (iii) variance distortion. SD would be in the range [-1, +1], i.e. it is equal to +1 if and only if $x_i = y_i$ for all i = 1, 2, 3, …, N.

B. Discrete Fourier Transformation

Structural Distortion only produces discrete values for each frame. Using a standard FFT algorithm, we computed the *Discrete Fourier Transform* $X(k)$ of the respective quality measure samples obtained, i.e.

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{-j2\pi kn/N} \tag{2}$$

where $x(n)$ is the aperiodic discrete time signals for Structural Distortion (SD), k is the frequency index, n is the number of samples, and N is the total number of DFT points.

IV. Experimental Results

A static scene is one in which there is no perceptible motion that can be seen by the naked eye. Some examples are shown in Fig. 2. However, this would usually be indoors where the source of illumination is from an electric lamp. The static scene chosen was a power supply conduit (Fig. 2(c)) that was fixed against the wall. In the first experiment, the only source of light comes from an incandescent light source (OSRAM) – Fig. 3.

The same image quality measure was then computed for that from a set overhead fluorescent lamps fitted with magnetic ballasts.

(a) (b) (c)

Figure 2. Examples of inactive scenes

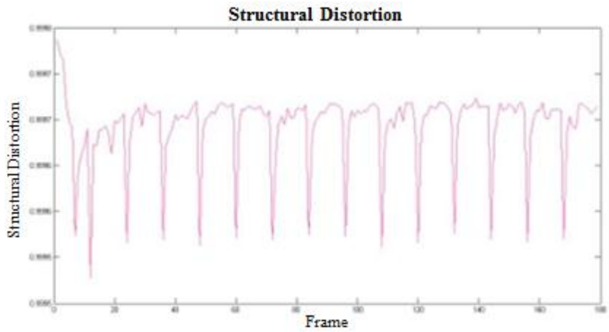
(a) Incandescent lamp (b) Close-up view of the filament

Figure 3. The OSRAM Incandescent lamp

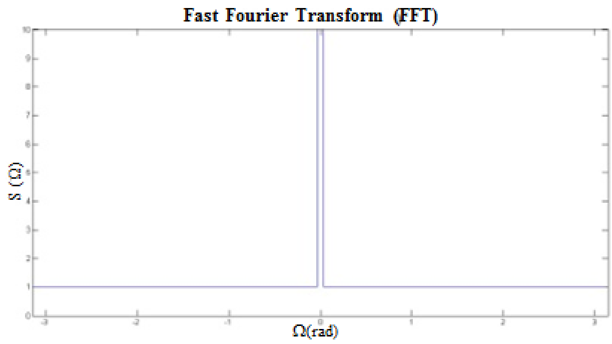
A. Incandescent Lamp

Video images of the scene shown in Fig. 2(c) were firstly captured at 30 frames per second (fps) with the incandescent lamp as the only light source. The *Structural Distortions* image quality measure was then calculated for the 180 frames of video images. These are shown in Fig. 4.

FFT on the Structural Distortion quality measure does not indicate any resemblance of periodicity.

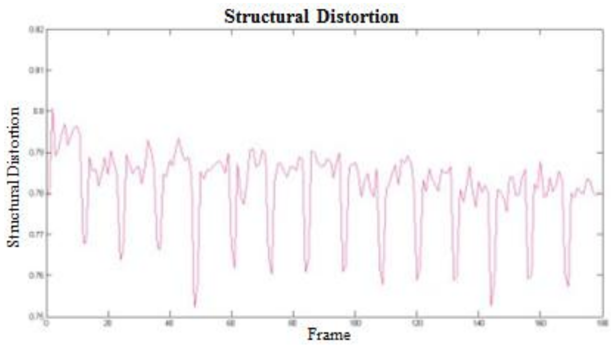


(a) Structural distortion

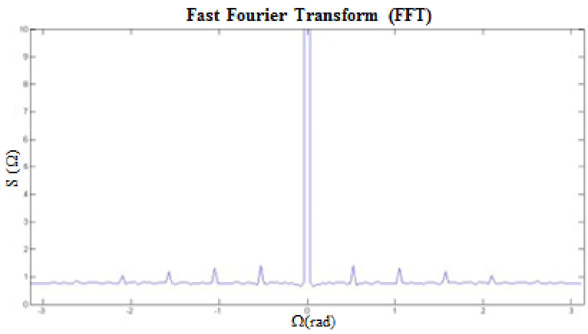


(b) FFT on structural distortion

Figure 4. Structural Distortion with the incandescent lamp as the only light source



(a) Structural distortion



(b) FFT on structural distortion

Figure 5. Structural Distortion with the fluorescent lamp as the only light source

B. *Fluorescent Lamp*

Video images taken at 30 fps were similarly processed to compute the *Structural Distortions* quality measure. These are shown in Fig. 5.

The quality measure was now able to record the periodic nature of the light intensity when its FFT was computed.

V. Discussions and Future Work

In this paper, we provide some analysis of the images of indoor scene that do not have any perceptible activities. The scene was illuminated with either one of two different types of electric lamps. This was used to analyse the flicker from either the incandescent or fluorescent lamps. In the case of the latter, they were fitted with a magnetic ballast. We have modeled this problem as one involving an image quality measure, specifically a Structural Distortion image quality measure. Using only a commonly available video camera, we were able to show significant fluctuations with the images that were illuminated with fluorescent lamp. Discrete Fourier Transform of this does show some interesting aliasing effects due to the sub-optimum sampling rate by the slower video camera. No similar effects can be seen for the incandescent lamp.

Future work will involve using these quality measures to look at the level of illumination from a fluorescent lamp fitted with an electronic ballast to evaluate and compare the level of illumination.

Moreover, the use of optical flow to detect illumination changes may be another approach. Even though optical flow is sensitive to any motion, nevertheless there is a prior assumption that there would be no motion within the scene. Hence this can be something that needs further investigation.

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