Detecting Non-lambertian Materials in Video

Seyed Mahdi Javadi, Yongmin Li and Xiaohui Liu
Department of Computer Science, Brunel University, London, U.K.

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Abstract: This paper describes a novel method to identify and distinguish shiny and glossy materials in videos automatically. The proposed solution works by analyzing the logarithm of chromaticity of sample pixels from various materials over a period of time to differentiate between shiny and matt textures. The Lambertian materials have different reflectance model and the distribution of their chromaticity is not the same as non-Lambertian texture. We will use this to detect shiny materials. This system has many application in texture and object recognition, water leakage and oil spillage detection systems.

1 INTRODUCTION

Object detection and texture analysis are important topics in image and video processing and have many applications in visual systems. In this paper we propose a new solution to distinguish matt and shiny surfaces. This method can be used to automatically detect water leakage, oil spillage, glass and metal detection etc. Unlike many of the exiting systems, no training data or manual interaction with user is need and glossy materials are detected automatically without any input from user. Our solution works in natural outdoor scenarios during day time where illumination varies. No additional information such as time and GPS location is needed and using stationary camera, successful detection is achieved in around 15 minutes of video recording.

Our method works by analyzing how different types of materials reflect light and use this to automatically categorize textures into Lambertian and non-Lambertian texture types. We use the logarithm of chromaticity of texture pixels over a period of time and show that matt and shiny materials display different patterns and trajectories and use this information for our detection algorithm. We plot the trajectory of logarithm of chromaticity and show that matt textures show linear pattern over time while glossy objects don't.

By analyzing the distribution of of reflectance from matt and glossy object, we can develop a system that can distinguish these materials. Additionally, we have used the same methodology to differentiate between glare and white objects. Glare or excessive reflectance impacts tracking and object recognition systems and here we have proposed a novel solution to detect and reduce the impact of glare in video.

The rest of the paper is organized as follow. Section 2 describes the background of this topic and Section 3 explains our method and describes how we are identifying glossy materials. Section 4 shows our experiments and section 5 is the summary of this paper.

2 LITERATURE REVIEW

Texture analysis is an important topic in image processing. Malik and Liuin (Malik and T.Leung, 2001) categorized different materials such as concrete, rug, marble, or leather on the basis of their textural appearance and they devid them into two surface attributes: (1) reflectance and (2) surface normal. In their work they provided a unified model to address both these aspects of natural texture. Get et al. (Ged et al., 2010) presented gloss as an appearance attribute that could reveal certain information about object properties and concluded that observers can apprehend the physical nature of the surface of real objects from features that are included in the BRDF and available in the gloss appearance. Obein (Knoblauch and Viot, 2010) provided a measurement to calculate the strength if gloss which they explained it as attribute of visual appearance that originates from the geometrical distribution of the light reflected by the polished surface. they used the maximum likelihood difference scaling (MLDS) procedure by Maloney (Maloney and Yang, 2003) to estimate gloss scales over an extended range.

Arora (Arora and Werman, 2014) presented a new approach to evaluate the illuminant chromaticity

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which does not need exact correspondences and has a better estimate of illuminant chromaticity. They used the evaluated chromaticity to project the input images on to a specular invariant color space and showed that standard optical flow algorithms on this color space significantly improves the results. Other works such as (Prinet et al., 2014),(Yoon and Kweon, 2006) and (Yang et al., 2011) provide similar approach to remove the impact of glare from glossy texture.

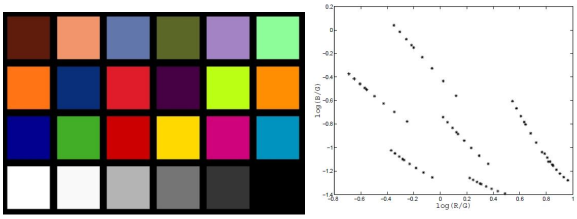
Multi-view solutions are has been extensively researched and they provide an alternative approach to the issue of irregular reflectance from glossy textures. Li and Liu (Li et al., 2011) reconstructed 3D fine-scale surface models for non-Lambertian objects from multi-view multi-illumination image sets. Their solution provides good results but requires multiple images from different angel to produce the 3-D model. This is a very effective and popular approach and many other works such as (Basri and Jacobs, 2003) , (Hertzmann and Seitz, 2005) and (Schechner et al., 2007) have used the same method. Although muti-view methods produce good results they require users to take pictures from different angels manually. Unlike these methods, our system detects the non-lambertian texture automatically and does not need any manual interaction.

Texture analysis is a very important topic in image and video processing and has many application such as road detection (Amini and Karasfi, 2016),(Zhang et al., 2015),(Munajat et al., 2015),(Hariyono and Jo, 2015) which is very popular in road traffic surveillance systems. Human detection is another popular use case for texture analysis in image processing. Kim and park (Kim et al., 2007) proposed an algorithm to recognize human presence with USB Web camera. Their method detects human movement using the circle detection and morphological methods. There are similar studies for human detection such as (Kahily and Sudheer, 2016) and (Sharma et al., 2016) where authors used neural network based training methods for human detection.

In this paper we are focusing on detecting glossy and shiny textures in outdoor scenarios and this solution can be used to detect water, oil leakage metal and glass in natural environments.

3 NON-LAMBERTIAN MATERIAL DETECTION

If we image a set of coloured surfaces under Planckian light, in a controlled light box and if surfaces are Lambertian and not shiny, then for each colour the log of the chromaticity r,g will be presented as a single dot



(a) (b)

Figure 1: (a) Macbeth colour chart (b) Plot of each colour on Log(B/G) and Log(R/G).

in a 2-d plot As displayed in Figure 1.(b)

This is because the RGB colour ρ for each of the tree channels K where K = (R, G, and B) is given by:

$$\rho_k = Ic_1\lambda_k^{-5}e^{-(c_2/T\lambda_k)}S(\lambda_k)q_k \qquad (1)$$

Assuming that lighting can be approximated by Planks law, constants c_1 and c_2 are equal to 3.74183 $\times$ 10^{-16} Wm^2 and 1.4388 $\times$ 10^{-2} mK. The variable I controls the intensity and $S(\lambda_k)$ is surface spectral reflectance function. Now to form band-ratio chromaticitys from colour values ρ,

$$r_k = \frac{\rho_k}{\rho_G} \qquad (2)$$

We divide this by green and calculate $\frac{R}{G}$ and $\frac{B}{G}$ to remove the intensity information and by doing this, the intensity information I will be removed. In addition to remove the temperature term, the log of equation 4.2 will be taken to form:

$$r'_k = log(r_k)log(s_k/s_N) + (e_k - e_N)/T \qquad (3)$$

In this equation, $s_k = c_1\lambda_k^{-}5S(\lambda_k)q_k$ and $e_k = -c_2/\lambda_k$ and when temperature changes, the 2 vectors r and k will form a straight line. In this paper, we have called this Logarithm of Chromaticity Ratio line or LCR line.

Since this behavior is only produced from materials which fit into Lambertian model, we can use it to distinguish between Lambertian and non-Lambertian surfaces.

3.1 Detecting Shiny Texture using LCR Line

The graph that was displayed in Figure 1.(b) was produced from a Macbeth colour chart in a controlled laboratory environment under a single light source. In real-life outdoor scenarios, the Illumination Reflectance Line is not as perfect as displayed in Figure 1 (b). The reason for this mismatch is although the illumination from sun to dominant, there are other sources of light such as reflectance from other nearby objects as well as sudden changes to the illumination due to clouds or other moving objects.

By adopting a Lambertian model of image formation so that if light source with a spectral power distribution (SPD) denoted *E(λ, x , y)* is incident on a surface which surface reflectance function is denoted *S(λ, x , y)* then the response of the camera sensors can be formulated as:

$$\rho_k(x,y) = \sigma(x,y)\int E(\lambda,x,y)S(\lambda,x,y)Q_k(\lambda)d\lambda \quad (4)$$

where $Q_k(\lambda)$ is the spectral sensitivity of the k camera sensor, k = 1, 2, 3, and $\sigma(x,y)$ is a constant factor which represents the Lambertian shading term at a given pixel. In previous section, it was explained that assuming the surface has Lambertian characteristics, plotting Log (R/G) and Log (B/G) would form a line which will be orthogonal to lighting source.

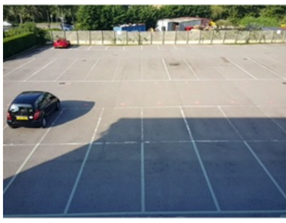
Here we present a novel idea to discover non-Lambertian materials such as glass, water, metal or any shiny material in the video under natural lighting condition. The approach that has been taken here is producing a plot from Log (R/G) and Log (B/G) of different regions and various pixels in the video to see if they fit in the Lambertian model and then check if they produce a line.

Now we change the approach and claim that the objects that their chromaticity don't fit into the linear model of $gs = c_1R'(R) - c_2R'(B)$ should not be matt. Therefore projecting $R'(R) = log(R/G)$ and $R'(B) = Log(B/G)$ would be able to display if the surface chromaticity is fitting into Lambertian model or not. This is explained in the following example:

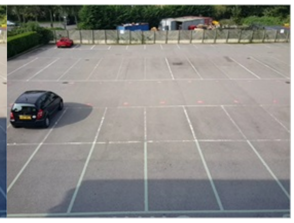
In this experiment 9 pixels were analysed and the trjecotry of their Log(R/G) and Log(B/G) were compared. The 9 samples are from these 3 categories : 1) Shadow area 2) non-shadow 3) sample from black car. These samples are marked from A-I in Figure 5.1 (c). The duration of this video is 1 hour and the plot of Log (B/G) and Log (R/G) of these 9 pixels over one hour is displayed in figure 5.2

The important observation here is the pixels which belong to Lambertian surface model i.e. matt materials show linear trajectory overtime. This is true regardless of the sampling position weather the pixel belongs to shadow or nonshaow region. However the pixel which belong to non-Lambertian surface model i.e. shiny materials such as water, glass or metal do not fit into this model and their chromaticity doesn't show linear pattern when illumination source changes.

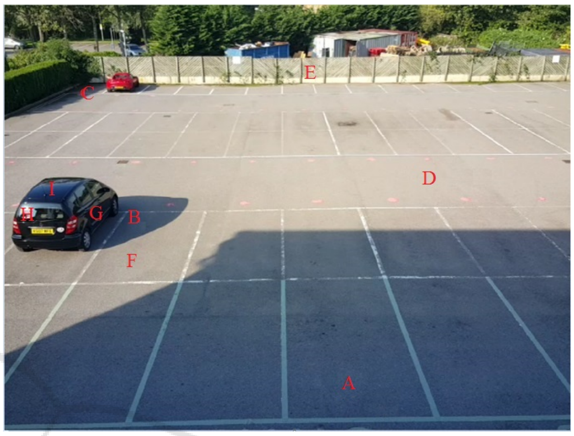
This behaviour can be seen in Figure 3. The first two rows show the chromaticity of matt objects in both shadow and nonshadowed part of the image and the 3rd shows the same analysis for shiny objects. In this experiment the matt regions show linear chromaticity over time whilst the shiny materials don't. This important characterised can be used to discover and distinguish shiny and matt textures in the video.



(a)



(b)



(c)

Figure 2: (a) First frame of the video (b) last frame of the video (c) 9 different pixels from three categories are selected for analysis. A, B, C are in shadow, D, E, F from none shadow, G, H , I are from the shiny parts of the car.

Another example is shown in Figure 4 where pixels from matt surfaces show linear chromaticity over time (both shadow and nonshadowed regions). But on the other hand, pixels from glass windows and doors where don't fit into non-Lambertian model do no show any linear trajectory over time.

Hence by plotting $R'(R) = log(R/G)$ and $R'(B) = Log(B/G)$ we can successfully distinguish matt and shiny textures over time because matt materials show linear pattern whilst shiny materials don't fit into any linear model.

Another interesting observation is seeing the difference between Figure 3,4 and 1.(b). The trajectories illustrated in Figures 3 and 4 are from real life scenarios where the illumination changes are not as con-

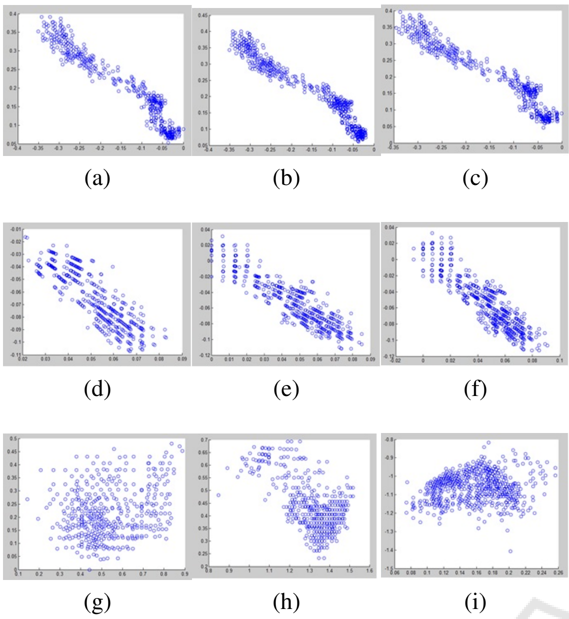


Figure 3: First row figures shows the trajectory of pixels (a) , (b) and (c) in Figure 5.1 over 1 hour of video which belong to shadow region. Second row displays the pattern of pixels (d), (e) and (f) which are from nonshadowed region of the image. 3rd row shows the trajectory of pixels (g), (h) and (I) which are from shiny metal and glass.

Figure 4: The 1st and last frame of the video taken outside Brunel university library.

trolled and regulated as lab lighting conditions which can be seen in Figure 1.(b). In natural outdoor conditions, the presence of additional sources of light and reflectance as well moving objects and clouds creates illumination noises hence the trajectory of matt texture will never be a perfect line similar to Figure 1.(b) and mostly it will be some scattered dots around the LCR line.

3.2 Logarithm of Chromaticity

In previous section we explained that plotting *Log (R/G)* and *Log (B/G)* of Lambertian material would form a line which called it LCR and it will be orthogonal to lighting source. We also explained that materials and textures that don't fit into the linear model of $gs = c_1 R'(R) - c_2 R'(B)$ are not matt and therefore projecting $R'(R) = log(R/G)$ and $R'(B) = Log(B/G)$

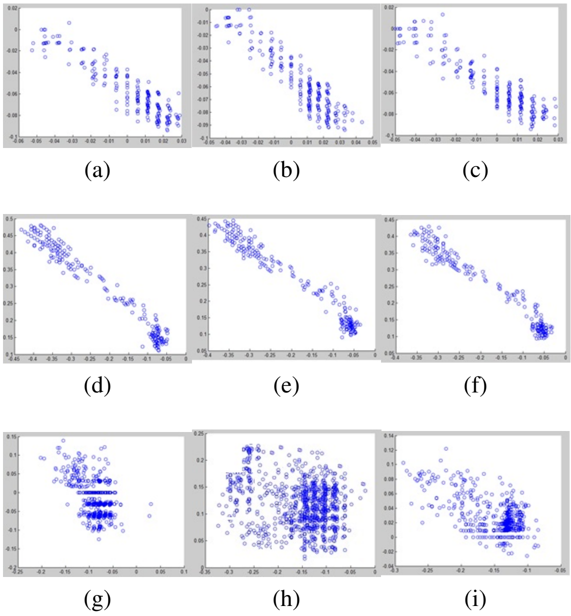


Figure 5: The 1st row figures shows the trajectory of pixels taken in shadow region. 2nd row displays the pattern of pixels from nonshadowed region of the image. The last row images show the pattern of the trajectory of pixels from glass doors and windows.

would be able to display if the surface chromaticity is fitting into Lambertian model or not. Reflectance and glares are one of the examples that don't fit into the following model:

$$\rho_k(x,y) = \sigma(x,y) = \int E(\lambda,x,y)S(\lambda,x,y)Q_k(\lambda)d\lambda \tag{5}$$

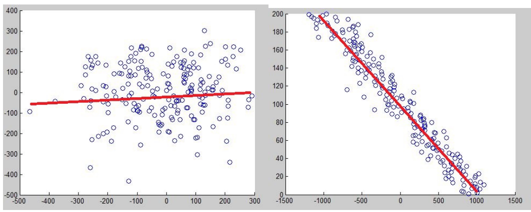
This methodology is illustrated in figure 6. In this example both the white paper and the mirror have saturated all tree channels and the value of their RGB is close to 255 however during the 15 minutes of recording, their logarithm of chromaticity shows a different trajectory and this can be used to distinguish the white paper (matt surface) from the mirror (shiny surface). To deploy this automatically we try to form a line from $log(R/G)$ and $Log(B/G)$ values using a smoothing filter from trajectory of both matt and shiny surfaces.

In Figure 7. The distribution of chromaticity values near the line of best fit is displayed for the mirror and white paper.

3.3 Using Line of Best Fit to Detect Glossy Materials

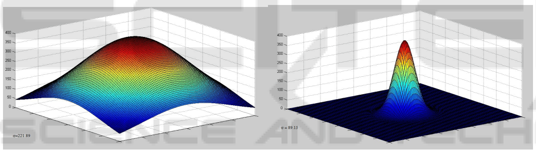
To distinguish white matt objects from reflectance we draw a line from scattered data and calculate the normal distribution of the logarithm of chromaticity of

(a)



(b) (c)

Figure 6: (a) The RGB value of both objects are close to 255 and both surfaces are white (b) logarithm of chromaticity of mirror over a period of time (C)logarithm of chromaticity of white paper which forms a line. In this example the σ of white paper is 89.15 but it is 221.89 for the mirror.



(a) (b)

Figure 7: (a) The ratio of change of logarithm of chromaticity of a shiny surface (b) at The ratio of change of logarithm of chromaticity of a matt material.

both surfaces. The σ of shiny surface is significantly higher than matt material. There are many materials and research in the field of statistic about interpolating scattered data. For the simplicity we used the Vandermonde matrix, $\boldsymbol{V}$, whose elements are powers of $\boldsymbol{x}$. $v_{i,j} = x_i^{n-j}$

We used Matlab to find the coefficients of a polynomial $p(x)$ of degree n that fits the data, $p(x(i))$ to $y(i)$,in a least squares sense. The result p is a row vector of length $n+1$ containing the polynomial coefficients in descending powers:

$$p(x) = p_1x^n + p_2x^{n-1} + \ldots + p_nx + p_{n+1} \qquad (6)$$

To fit a straight line, then $n = 1$, and the equation would be:

$$p(x) = p_1x + p_2 \qquad (7)$$

By using Vandermonde matrix based function of polyfit in Matlab, we can produce p_1 and p_2 and when the line of best fit is identified, we calculate the distribution of logarithm of chromaticity and use σ to differentiate between matt and glossy objects. This is explained in the following algorithm.

Algorithm 1: How to differentiate between white materials and reflectance.

1: Plot the gradient of $R'(R) = log(R/G)$ and $R'(B) = Log(B/G)$ from saturated regions using the available frames.
2: Produce the line of best fit .
3: Produce the normal distribution of all the logarithms of chromaticity.
4: The σ of the distribution of the shiny material will be higher than matt surface and this indication can be used to distinguish these two object material.

An important advantage of this method is it is completely independent of colours and the RGB values will not impact the distribution of chromaticity. The only material characteristic which will have impact on the distribution is glossiness of texture. Therefore this algorithm can be used to successfully detect all different types of shiny surfaces.

4 CONCLUSION AND FURTHER WORK

In this paper we have provided a novel solution to automatically detect non-lambertian materials in video. Our method works by analysing the logarithm of chromaticity of pixels over time and checking their distribution around a straight line which is orthogonal to lighting direction.

We showed regardless of the colour of the materials, the matt and glossy textures show different behaviors when the logarithm of their chromaticity is analyzed for a period of time and this can be used to automatically detect objects such a water, glass or shiny metal. This solution can have many applications in video and image processing systems such as water detection, oil leakage detection and many more. Unlike some of the existing methods, training data or manual or semi supervised user input is not required.

One way to continue this work would be to use the colour information and other features of textures to identify various types of glossy objects. Water, glass and metal have different characteristics which can be used to differentiate one from the other.

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