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MASTER THESIS WORK

FAST MEASUREMENT OF DIFFUSING PATTERNS AND ITS PARAMETERIZATION

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Fast measurement of diffusing patterns and its parameterization

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Abstract. When light strikes on a diffuser surface a new energy redistribution is created. The diffusion patterns depends on the material of the diffuser and how light reach the diffuser. The aim of this project is to characterize a simple and compact system that allows us to obtain transmission patterns of different diffusers in order to make a mathematical, experimental fitted, model of them. After define, and construct the experimental device a first characterization step is done; this steps covers a geometrical, photo-temporal and photo-spatial characterization of the system; with the experimental device well characterized a set of six different diffusers are analyzed obtaining the equations that describe their diffusion patterns.

Keywords: Diffusion models, characterization procedure, diffusion patterns

1. Introduction

Diffusers are materials or surfaces that produce diffusion or scattering, the process by which the spatial distribution of a beam of radiation is changed when it is deviated in many directions without change of frequency or of its monochromatic components [1]. Diffusers are part of our daily life, haze and clouds that block the sun act as diffusers; we do not see the sunlight directly but the diffused rays. They are employed in very different applications, from devices as LCDs of computers or mobile phones to sunroofs and hazed glasses [2,3]. They are commonly used in photography and lightning in order to get good levels of illumination and uniformity and can be as simple as a piece of glass or plastic placed between a light source and the item that has to be illuminated.

Although diffusers can be apparently simple devices, they have to accomplish many conditions that can be very different between devices so good parameterization of them is important. They can be studied by different approaches depending on the information that we want to extract and the complexity of this information. One way of study and design diffusers is by ray tracing, this approach studies how the flux of light transported by every ray reaches the surface and it is reemitted [4]. Another way is by the radiative transfer equation [3]. Both methods are complex hence a simpler method was searched as it is explained in [5]. In this case a radiometric approach is used, the energy is studied by investigating the radiant energy emerging from an elementary surface portion [5] without taking into account the rays but for image translation; the quantity of energy and the distribution that reaches a sensor is analysed for obtaining information about the diffuser.

The aim of this work is to develop a simple device and a fast method for obtaining and parameterize diffusion patterns regarding the energy distribution. The whole procedure consists in two steps. Firstly, the characterization of the device related with the distortion and the losses of the optical system taking as a reference a Lambertian source. Secondly, similar to [5], the acquisition of images of diffusion patterns and the analysis of cut plots of the images in order to obtain a model that describes the energy distribution of the diffused light that reaches the sensor.

2. Experimental setup

The constraints for the device were to be a simple and compact device capable of capturing images of diffusion patterns of different materials for the later analysis of them. The device needed to be a quite small one, with some place to put the samples taking into account that their thickness could be variable. It also needed to have some light isolation from the surroundings in order to not to capture external light that would interfere in the diffusion patterns when working in an illuminated space and its own light source to illuminate the sample.

Taking into account the general characteristics that the device should had, the experimental setup used for the characterization of diffusers is the one described in figure 1. The light source is a white LED followed by a 1mm pinhole that collimates the light in a fine beam. The quasi-collimated beam is focused into the diffuser under study. The light passing through the diffusers produces a diffusion pattern in a screen made of a Lambertian diffuser. Finally, the images projected in the screen are captured by a camera (Guppy AVT Guppy PRO F503B) with a CMOS sensor with a pixel size of 2,2μm, situated at the end of the system.

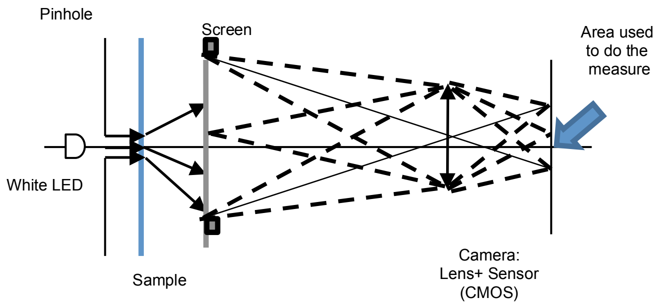
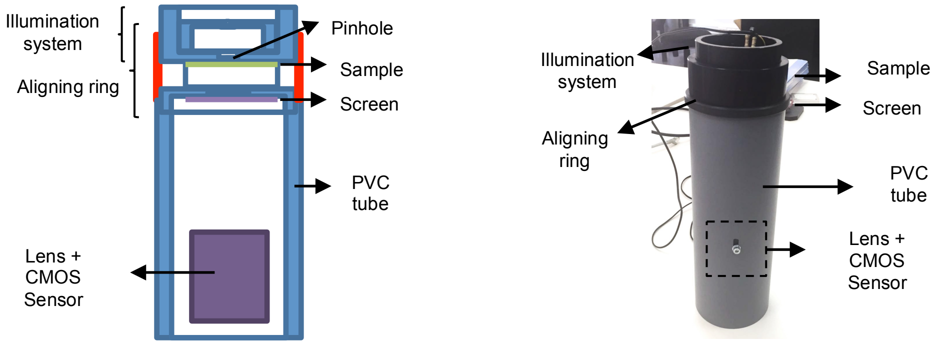


Figure 1. Scheme of the set-up used where we show the light source followed by the pinhole and the quasi-collimated rays that reach the sample; the diffused light reaches the screen and the sensor captures the diffusion pattern. Pay attention that the Screen is also a diffuser that redirect enough light to the entrance pupil of the lens+sensor to capture the image of the screen, this kind of arrangement forces a calibration process of the entire device.

However, the final setup was not mounted in an optical bench but it was a closed device with the system isolated from the external light. The system was mounted in a PVC tube as can be appreciated in the figure 2(b); as it is an opaque material we prevented the external light to get into the system. The remaining pieces were made of on massive black PVC and aluminium and consisted on several rings of different diameters. As can be observed in the figure 2 on the top was placed a first ring with the illumination system inside and in the same piece the 1mm pinhole was placed. Right after de pinhole the sample is situated and after another ring where the screen is placed at the end; both rings are joint by a bigger ring that is the aligning ring. After the set of rings the PVC tube begins and inside of it the camera is mounted with an massive black PVC support; in order to focus the image properly there are three slots in the PVC tube to adjust de distance between de camera and the screen as can be seen in the figure 2(b).



(a) (b)

Figure 2. (a) Scheme of the device considering all the pieces of the mounting and image (b) of the real device where we can see the set of rings (in black) joint to the PVC structure and the slots in it in order to move the camera and focus the images.

3. System characterization

The characterization has been done at three levels: Geometrical characterization, photometric temporal characterization and photometric spatial characterization.

3.1. Geometrical characterization

The geometrical characterization in this case is based on the study of the distortion, which is defined as the lack of constancy of the lateral magnification along the image. The distortion was studied using a 30x30 squares grid with squares of 2mm side. It was studied in the horizontal direction in order to simplify the calculus and taking into account that the whole process of analysis of the scattering patterns would be done in this direction. For a more precision in the calculus of the distortion function, four pictures of the grid were analysed, each one with a rotation of 90º respect the previous one. The process followed for each of the four images is the following one:

3.1.1. Size of the squares. The first step was to know the side size of the squares on the grid in the image taken by the system. Using a profile plot of a horizontal cut of the image we knew the size of each square. In the profile plot (see figure 3) every minimum peak represents a vertical line of the grid; hence, by measuring the number of pixels between each minimum peak and the following one, the size of every square could be known. However, since every vertical line is represented by more that one pixel in the image, a curve fitting was done in every minimum peak and the pixels in the surrounding in order to establish a more real position of the line and therefore a more real size of each square.

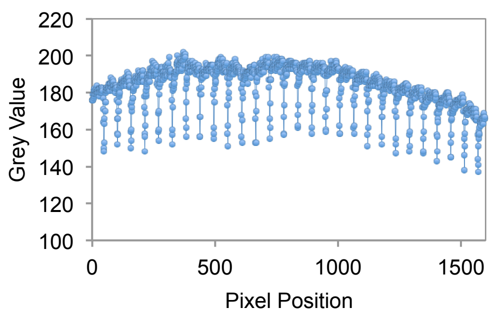


Figure 3. Profile plot obtained of a horizontal cut of the grid. Each minimum peak represents a vertical line of the grid.

3.1.2. Finding the ideal position of every line. Once we knew the real position of each line the ideal position of them in a system without distortion had to be found in order to compare both real and ideal position and obtain the distortion function. For the calculus of the ideal position three parameters where defined: zero, origin and period. Zero is the central pixel of the images taken, Origin is the pixel where the minimum peak closest to the zero is, and finally, the period (T) is the number of pixels that exists between the two minimum peaks closest to the zero. Using these three parameters in the equation 1 we could find the parameter reference (REF) in order to find the ideal position of each vertical line in the grid using the equation 2.

$$REF = N + \frac{zero - origin}{T} \quad (1)$$

$$Ideal\ position = (N - REF) \cdot T \quad (2)$$

3.1.3. Recentering the points. In order to obtain the distortion function, we represented the absolute value of the increment of the real position of each line respect the ideal one (see figure 4). By fitting a 3th order polynomial equation in the experimental points we could know where is the distortion symmetry centre of the image and that way we could reposition all the points respect the new centre, that was given the position 0.

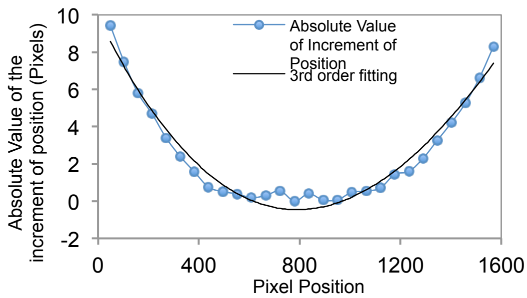


Figure 4. Graphic that shows the relationship between the absolute value of the increment of position of each pixel respect the ideal position for every pixel (in blue) with and a curve fitting of 4th order (in black).

3.1.4. Obtaining the distortion function. At this point the data obtained for all the images is put together in order to obtain a global distortion function. We needed to obtain a 5th [6] order curve that relates the increment of pixel of every position with the new position respect the new centre found in the previous step (see figure 5).

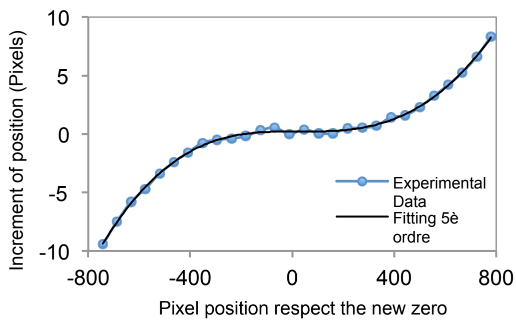


Figure 5. Graphic that relates the position increment of each pixel with the position that has in the image (in blue) and a 5th order fitting curve (in black).

Using the first derivative of the 5th fitted curve we obtained a 4th order equation that describe the distortion of the system. Equation 3 describes the distortion of the system and was obtained by using the data in the figure 6.

$$f(x) = -2{,}8129 \cdot 10^{-12}x^4 - 2{,}5638 \cdot 10^{-10}x^3 + 6{,}9237 \cdot 10^{-6}x^2 - 0{,}00010342x + 0{,}0087736 \quad (3)$$

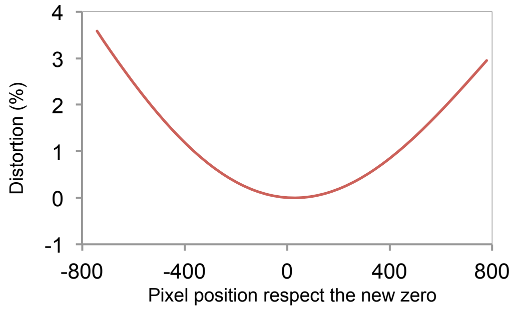


Figure 6. Graphic that represents the function that describes the system's distortion. The y-axis represents the rate of distortion in every pixel. The x-axis represents the pixel position. In this case there are no experimental points in the graphic since the equation was obtained from the fitting curve in the figure 4.

The equation 3 was the one applied to the images of the diffusion patterns in order to correct the distortion.

3.2. Photometric temporal characterization

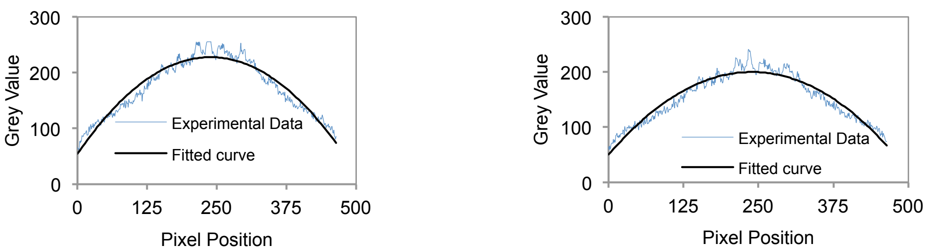
The aim of this step is to check that exists linearity between the exposure time of the images and the level of digitalization; hence the plot profile shape obtained for each scatter pattern will not depend on the exposure time.

First of all, we took four images with the system of a Lambertian diffuser with a variation in the exposure time between each image (see figure 7) and as in the previous section we studied the profile plot of a horizontal cut of the image.

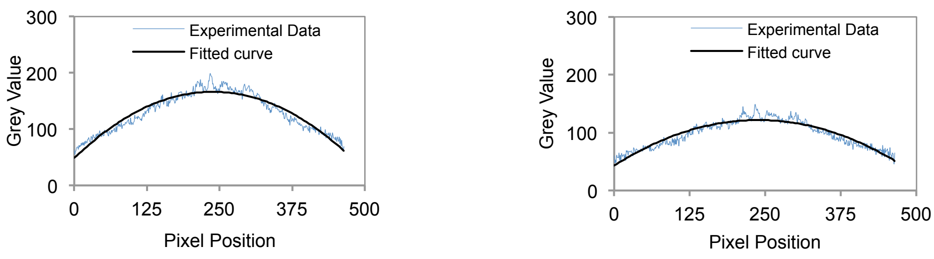
(a) (b) (c) (d)

Figure 7. Images of the diffusion pattern obtained with a Lambertian diffuser as sample. (a) Exposure time 5280µs; (b) Exposure time 3920µs; (c) Exposure time 2560µs; (d) Exposure time 1200µs.

A curve fitting was done in each profile plot adjusting a 2nd order curve (see figure 8) and then the four curves were compared in order to verify the linearity between the mentioned parameters.



(a) (b)



(c) (d)

Figure 8. Graphical representation of the profile plot of the curs in the figure 7. Each profile plot has a 2nd order function fitted. (a) Exposure time 5280µs; (b) Exposure time 3920µs; (c) Exposure time 2560µs; (d) Exposure time 1200µs.

In order to see clear the linear relationship we represented the maximum grey level obtained for each exposure time in the figure 9 with which we can verify that it does exist linearity between the parameters.

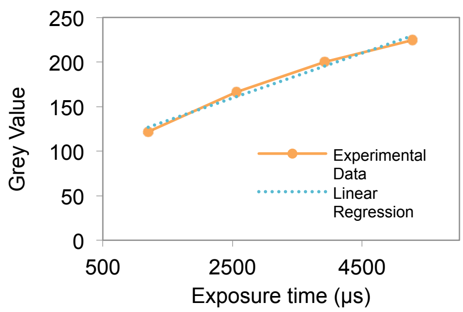


Figure 9. Graphic that relates the maximum grey level of each image with the exposure time with which were taken and shows the linearity between the values.

3.3. Photometric spatial characterization

In the third and last step of the characterization of the system we studied the losses of the optical system taking as a reference a Lambertian diffuser. To do it we took one of the images of the previous section.

Before comparing the curve of intensities with a Lambertian source the distortion correction of the section 3.1 was applied as well as the conversion from pixels to angles, since the losses have angular dependence. Taking into account these conditions we did the comparison between the curve obtained experimentally and the one described by the Lambert's cosine law [7]

$$E_\theta = E \cdot cos\theta \quad (4)$$

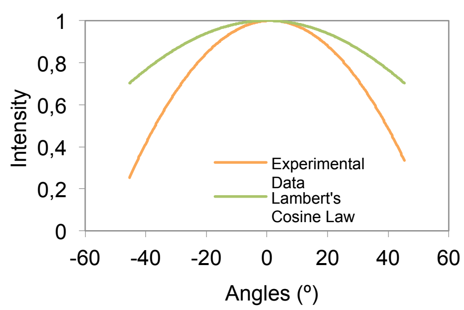


Figure 10. Graphic that compares the light intensity distribution of a Lambertian diffuser acquired with the system (orange) and the theoretical distribution following the Lambert's cosine law (green).

With the difference of intensity between the experimental and the theoretical curve we obtained an equation of correction of the intensity in order apply it to the data obtained from the images of diffusion patterns.

$$f(\theta) = 0{,}00019716\theta^2 - 0{,}00090176\theta - 0{,}0007923 \quad (4)$$

4. Selection of samples and measures

4.1. Presentation of the samples

For the parameterization of diffusion patterns six samples of diffusers were selected, however only the four with the most significant results are presented. All the samples were provides by CD6 and where extracted from Rosco Cinegel filters catalogue [8] that describes them as:

4.1.1. Light Grid Cloth. A reinforced diffusion material that is similar to the silk used in butterflies and overheads. Ideal for tenting and large area diffusion.

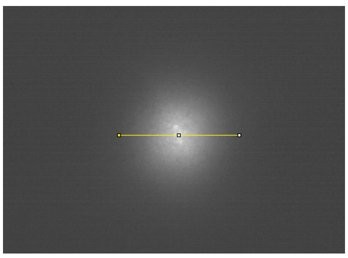
4.1.2. Tough White Diffusion (216). A moderate diffuser with properties similar to tracing paper. Creates an even field of soft light with minimal colour temperature shift. Tough, heat resistant base.

4.1.3. Tough Rolux. A dense diffuser that creates an even field of soft, "shadowless" light. Excellent for combining multiple lighting fixtures into a single, large area source. Tough, heat resistant base.

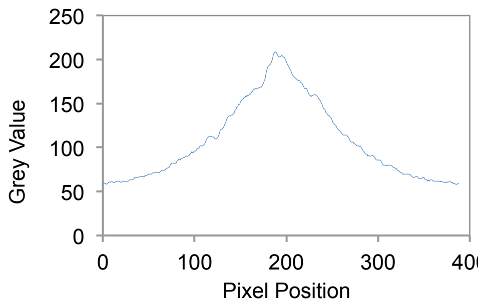
4.1.4. Tough Frost. A medium diffuser that spreads the beam yet maintains a centre. Tough, heat resistant base.

4.2. Step-by-step process

4.2.1. Acquisition of images and profile plot extraction. The acquisition of the images was done by placing each sample in the device that was built. For each sample the time exposure was adjusted in order to get proper intensities in the image and be able to analyse it. Once acquired the image a mean filter was applied in order to denoise the image and obtain a smoother curve. Finally, once the image was corrected a profile plot of a horizontal cut of the diffusion pattern was obtained (see figure 11).



(a)

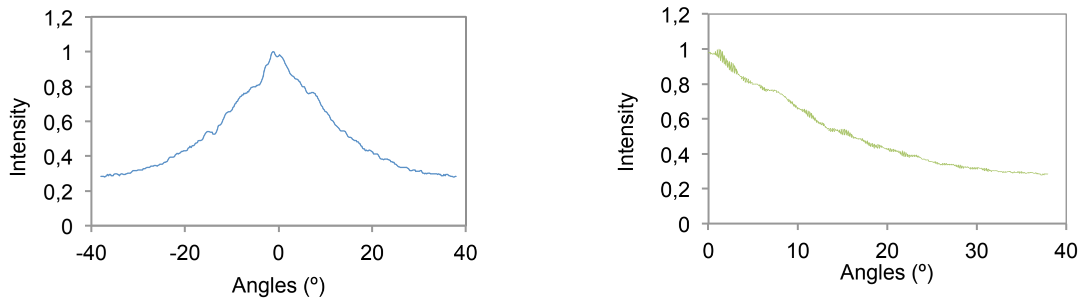


(b)

Figure 11. (a) Image of a diffusion pattern with the horizontal from which we extracted the profile plot in (b).

4.2.2. Curve correction. Taking into account that exist some distortion and loss of intensity respect a Lambertian source, some corrections had to be applied in the profile plot using the equations obtained in the characterization. Besides, we wanted to express the equations in function of the angular position respect the centre of the diffusion pattern; therefore we needed to first re-centre the pixels and then convert the pixel position to the angular position.

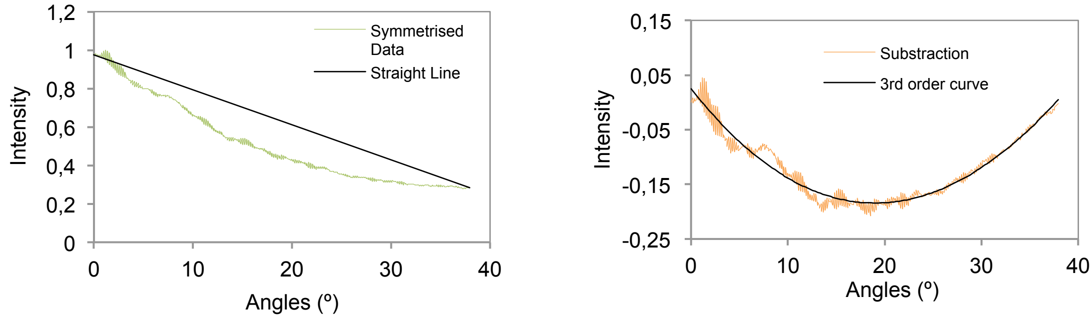
4.2.3. Symmetrisation of the profile plot. Once we have the curve corrected we needed to prepare it to do the curve fitting. We considered that the diffuser scatters the light symmetrically then we can symmetrize the profile plot in order to ease the process of fitting (see figure 12).



(a) (b)

Figure 12. (a) Original profile plot of an horizontal cut o a diffusion pattern. (b) Symmetrised profile plot.

4.2.4. Curve fitting. Since the function that fits the experimental data is not a simple one, the curve fitting process was done in two parts. First of all, a straight line passing by the limits of the curve was drawn (figure 13a) and substracted from the initial function, then in the substracted data a curve is fitted searching the order that better matches (figure 13b)



(a) (b)

Figure 13. (a) Symmetrised plot with a straight line passing by the limits of the curve. (b) Substraction curve (orange) with a fitting curve.

The function that will define the model was the sum of the straight line and the curve obtaining an equation like

$$f(\theta) = A|\theta| + B + a|\theta|^3 + b|\theta|^2 + c|\theta| + d \quad (5)$$

that can be represented graphically as in the figure 14.

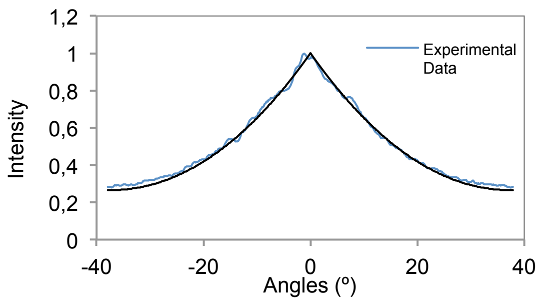
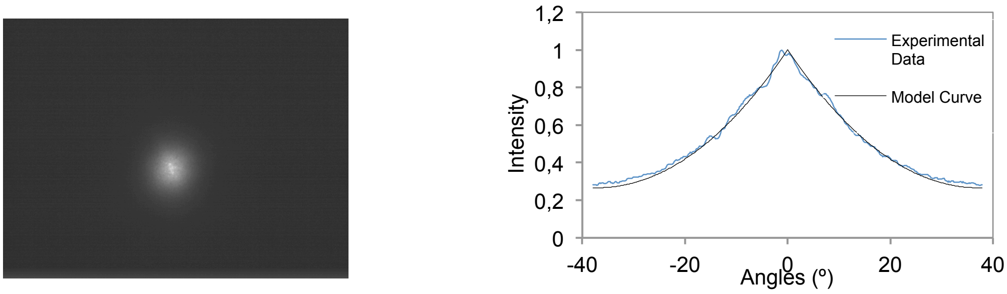


Figure 14. Curve that defines the diffusion model (in black) superposed to the profile plot of the pattern (in blue).

5. Results

The four most significant results obtained between six samples are presented in this section. For each sample the diffusion pattern, the experimental curve and model curve and its equation are presented.

5.1. Light Grid Cloth

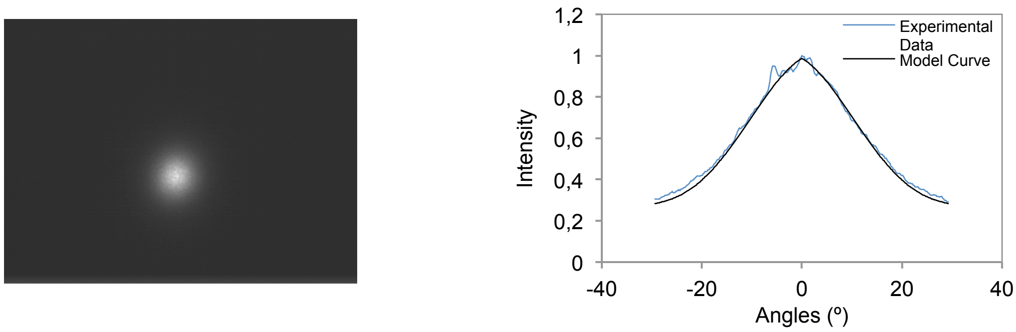


(a) (b)

Figure 15. (a) Image of the diffusion pattern of the diffuser "*Light Grid Cloth.*" (b) Curve that defines the diffusion model (in black) superposed to the profile plot of the pattern (in blue).

$$f(\theta) = 0{,}000001|\theta|^3 + 0{,}0006|\theta|^2 - 0{,}0407|\theta| + 1{,}0008$$

5.2. Tough White Diffusion (216)

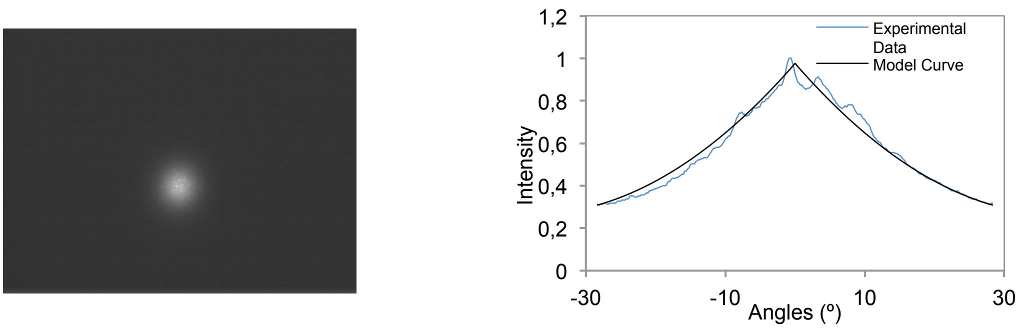


(a) (b)

Figure 17. (a) Image of the diffusion pattern of the diffuser "*Tough White Diffusion*". (b) Curve that defines the diffusion model (in black) superposed to the profile plot of the pattern (in blue).

$$f(\theta) = 0{,}2 \cdot 10^{-7}|\theta|^5 + 0{,}1 \cdot 10^{-6}|\theta|^4 + 0{,}8 \cdot 10^{-4}|\theta|^3 - 0{,}0023|\theta|^2 - 0{,}013|\theta| + 0{,}9848$$

5.3. Tough Rolux.

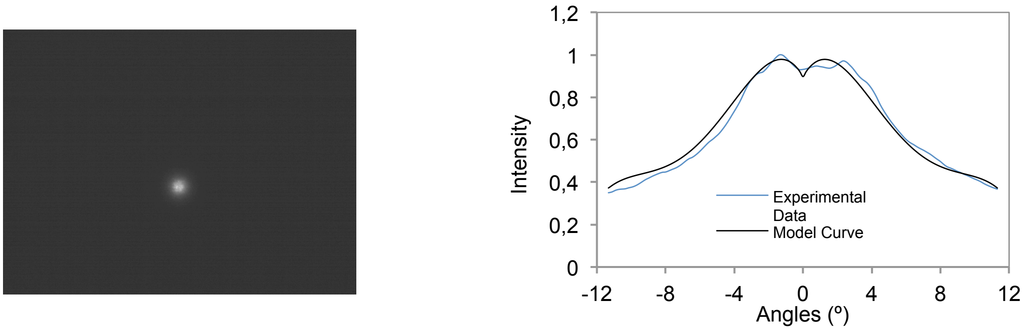


(a) (b)

Figure 18. (a) Image of the diffusion pattern of the diffuser "*Tough Rolux*". (b) Curve that defines the diffusion model (in black) superposed to the profile plot of the pattern (in blue).

$$f(\theta) = 0{,}5 \cdot 10^{-3}|\theta|^2 - 0{,}0377|\theta| + 0{,}9756$$

5.4. Tough Frost.



(a) (b)

Figure 19. (a) Image of the diffusion pattern of the diffuser "*Velvet Frost*". (b) Curve that defines the diffusion model (in black) superposed to the profile plot of the pattern (in blue).

$$f(\theta) = -0{,}3 \cdot 10^{-2}|\theta|^4 + 0{,}0081|\theta|^3 - 0{,}0697|\theta|^2 - 0{,}1398|\theta| + 0{,}8977$$

6. Conclusions

In conclusion, we have proposed a method for characterizing diffusers and its energy distribution by analysing their diffusion patterns. We have shown that two steps have to be followed in order to get the equations that describe the diffusion patterns; a first one related to the characterization of the system constructed in which the distortion of the system is studied as well as the losses respect a Lambertian source, and a second step directly related with the aim of the project, obtaining a model that describes the diffusion pattern. The results show that following the method described we can accomplish the aim of the project, however some limitations were found in case of very thin diffusers, in which the sensor was saturated by the light received.

7. Acknowledgements

I would like to thank my supervisor, Prof. Josep Arasa, for his help and guidance along the whole project.

8. References

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