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Wavelet-Based Processing of Angular Measurements: Application to Realistic Display Aspect Simulation

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ABSTRACT

In this paper, we describe a new wavelet-based data processing that performs simultaneously compression and fast multidimensional interpolation of hemispherical angular features. This algorithm is applied for display aspect simulation to allow predicting the rendering of any content on a given display under any illuminations conditions. Such rendering is based on a complex set of data composed of emitting display properties as a function of angle as well as its reflective behavior (BRDF).

General Terms

Algorithms, Measurement, Performance, Design, Human Factors.

Keywords

Display aspect simulation, viewing angle, wavelet transform, compression, multidimensional data interpolation, Tree diagram geodesic sphere, Fourier optics, BRDF.

1. INTRODUCTION

Nowadays flat panel displays consumers are more and more skilled in technology and demanding. It becomes obvious for anyone now that any flat panel display absolutely has to be tested under realistic conditions what means using it in the final place it is made for: outside ambient for mobile phone, in place in dashboard for embedded displays on cars or plane. Characterization in darkroom has now proven its insufficiency.

In this paper we will describe a software processing tool that uses measured data to simulate display rendering under realistic conditions, taking into account most of the display imperfections as well as environmental inescapable factors (sun light, dashboard shape). This is useful for color/contrast quality assessment and provides a wise help for display design.

Very few papers tackle the subject of image quality of displays under physico-realistic conditions. Farrell [1] proposed an evaluation of image quality from display simulation using three functions: the intensity response, the spectral response and the point spread response. However results are presented on axis only and don't take into account the specific non-uniform angular response in the case of flat panel displays. They cannot be used for the simulation of the display aspect for a user positioned anywhere in front of the display -meaning each pixel of the display is seen from a different (θ,φ) couple of angles-.

The angular behavior of a display is a key feature of its overall performances. ELDIM has introduced the Fourier optic instrument twenty years ago to allow fast and accurate angular characterization in terms of luminance, but also contrast, color and color purity [2-3]. Collecting such data makes it possible to simulate the display aspect for various positions of the observer (cf. fig 1). A first approach has been proposed in [4-5] analyzing the homogeneity of a display switched on in a uniform white. The usefulness of cartography of viewing angle measurements along the display has also been discussed.

Our concern here is about the screen aspect while displaying a given content (not simply full ON/OFF state but a full color image) and giving consideration to ambient light in order to have a realistic outlook of a given image. For the emissive behavior of the display, we therefore need not only ON/OFF state angular data but also R, G, B angular behaviors at multiple grey levels. To tackle the physic-realistic part of the simulation we need also to take into account the BRDF of the display surface. Defining a given ambient we can then simulate the unwanted ambient reflections that corrupt contrast and color. A little difference occurs here since for the emissive part we can only focus on X, Y, Z components of each R, G, B primaries. In the case of reflectance we have to consider it as a function of wavelength since the reflective phenomenon varies strongly with λ. Because of the required amount of data we use wavelet-based tree decomposition. Data are thus strongly compressed while remaining easily and quickly accessible for use in ray tracing software.

2. MEASUREMENT TECHNIQUE

Fourier optics based viewing angle instruments (fig 2.) have long been recognized as powerful tools to measure these important characteristics. Last generation of instruments are now able to measure the luminance and the color up to ±88° for all the azimuths on large spot size up to 6mm. Fourier optics has the capacity to transform the angular response in spatial information that can be imaged by a 2D sensor (cf. fig 3). The optical mounting patented by ELDIM allows adjusting the measurement spot size independently than the angular aperture. The consequence is that the measurement spot size varies with the angle. It is the so-called "cosine compensation". This unique feature allows getting a system transmittance above 60% even for very grazing angles. ELDIM range of equipment includes a reflective option that allows measuring the display BRDF [6].

3. MEASUREMENT EXAMPLE

As a first approximation we use here measurements at the center of the display only and suppose a good homogeneity of the angular behavior on the display surface. Since we have to evaluate

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separately R, G and B sub pixels, we need to use a big enough spot size to ensure accurate measurement: at least ten of ON State sub-pixel elements need to be included in the spot size. The display is measured in Red, Green and Blue and this for different grey levels (for example {0, 31, 63, 95, 127, 159, 191, 223, 255}). We can see on fig 6. some important variations versus grey level. Data have obviously to be compensated for black state what require also a measurement for a black pattern.

The reflective display properties are measured with the same instrument including the reflective option. The display is then illuminated across the Fourier optics with a white collimated beam along the desired incoming direction and the measured reflectance is normalized using a measurement on a reference white in the same illumination conditions. Measurement are made for different incidence angles and wavelength (cf fig 7) and results are assumed azimuth independent (isotropy of the display).

4. WAVELET-BASED MODEL

Many attempts have been done to build accurate models that correctly render angular reflective behavior of materials. None of them is universal enough to fit simultaneously any display emissions and display reflectances (specular, diffuse, haze…). That's why we choose to follow the work of L. Claustres [7] that had to cope with the same issues for the BRDF of surfaces in realistic scene rendering. Instead of choosing a model that is material-dependent and requires to be able to cope with the inverse problem (in order to identify the parameters of the model), we decide to start directly from the data and represent them by their wavelet coefficients allowing to compress strongly the data.

4.1 Angular wavelets

A large amount of work has been published on wavelet transform since 1975 when Morlett has proposed at first his time-scale representation which was shortly applied by Mallat to multi-level analysis. Many wavelets have then been designed on *R* and extended to R^2 : Daubechies, Morlett., Adelson, Battle-lemarie, Odegard Angular display emission and display BRDF are however defined onto the sphere S instead of R^2. Data processing makes it possible to use previous advanced wavelet basis by shifting from R^2 to S (and back) but the work is tedious. An alternative option is to use specific wavelets defined on S: they are not many, all derived from the original Haar one but have proven to be of adequate use in our case.

We therefore propose to make a tree decomposition of the sphere using a recursive subdivision of triangles as described in figure 8. At each step a (father) triangle is subdivided into 4 small (children) triangles. This means that the number of triangles used to map the half sphere depends on the decomposition level as follows: Nb triangles = 4^{i+1} , where i is the level of decomposition. Figure 4 shows the number of triangles and the angular resolution as a function of the decomposition level. At a given decomposition level, each leaf triangle corresponds to an entering or outgoing direction (aimed by the triangle center). The highest the subdivision of the sphere is, the smallest the deformation of the sphere is and the best angular resolution can be obtained. Figure 9 represents the decomposition level 0, 1, 2.

During the wavelet processing step –based on Haar multi-level data description-, each father triangle (step i) is evaluated as the mean of all its 4 children (step i+1). This average value is also stored in the central children whereas the "detail" information is stored in the other 3 children triangles as the difference between initial value and average value. The process starts from the highest decomposition level and goes up recursively into the decomposition tree. If no compression is performed this allows to perform the inverse process to find back exactly the original value for each leaf triangle. Fig 5 shows an example of reconstruction from a wavelet compressed set of data at level 3.

4.2 Spectral Data

As discussed previously any processing on BRDF requires taking care of the wavelength. For each incoming direction and outgoing direction we can therefore store a complete spectrum that can be compressed using a wavelet scheme. At that step, it is a well-known transform in the *R* space that is not correlated to the S transform. It can use any of the advanced wavelet basis previously mentioned.

4.3 Main key points

The interest of this approach lies into:

- A high compression efficiency: able to manage large data sets. Final files are 1% to 10% from initial ELDIM file (depending on the sphere subdivision level).
- A multi-resolution approach: a reconstruction at different levels of accuracy is possible
- The reconstruction efficiency: the reconstruction of the signal is done in a logarithmic time according to the number of samples. The major point is that data is reconstructed locally: the whole wavelet tree does not need to be inversed.
- Easy interpolation: this processing allows interpolation of data simultaneously on entering and outgoing direction as well as on the spectral dimension.
- Additional denoising: small and localized signal variations are automatically reduced by the compression

5. CONCLUSION

We have described the process used to compress and decompress the experimental data and explained its adequacy to display aspect simulation. The full software package is available for free for all potential users.

6. REFERENCES

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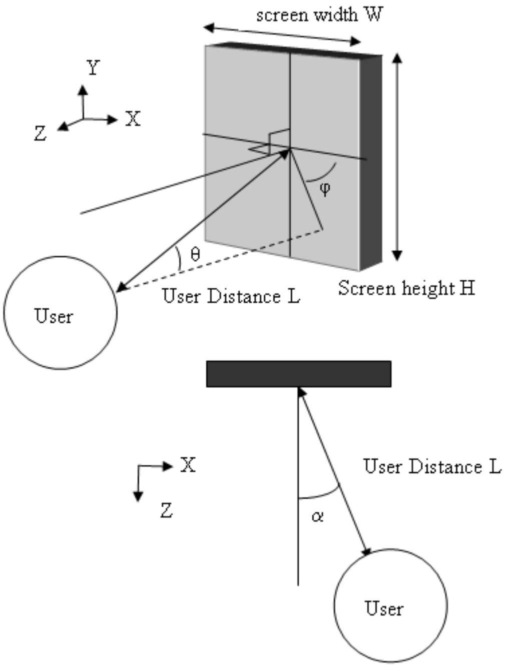


Figure 1: Display simulation parameters.

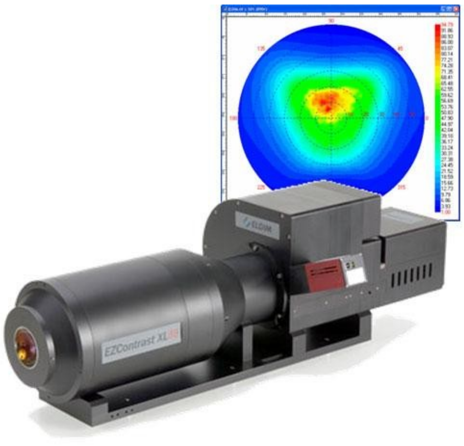


Figure 2: ELDIM Fourier optic equipment.

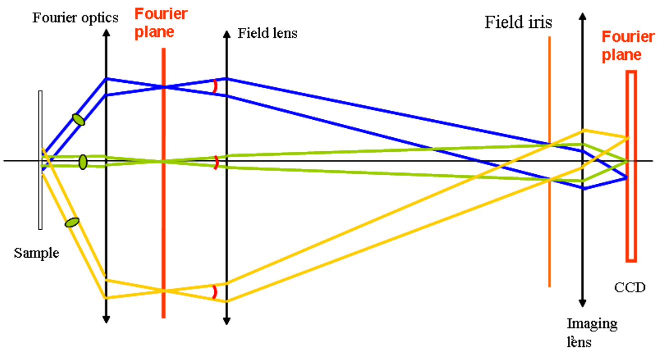


Figure 3: Schematic diagram of the ELDIM patented Fourier optics mounting for large angular aperture and independent control of the measurement spot size.

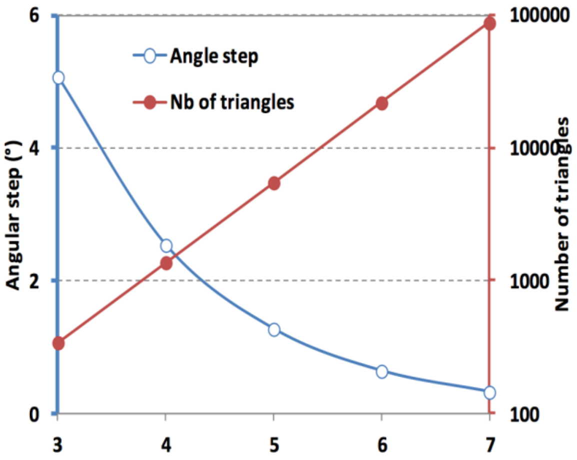
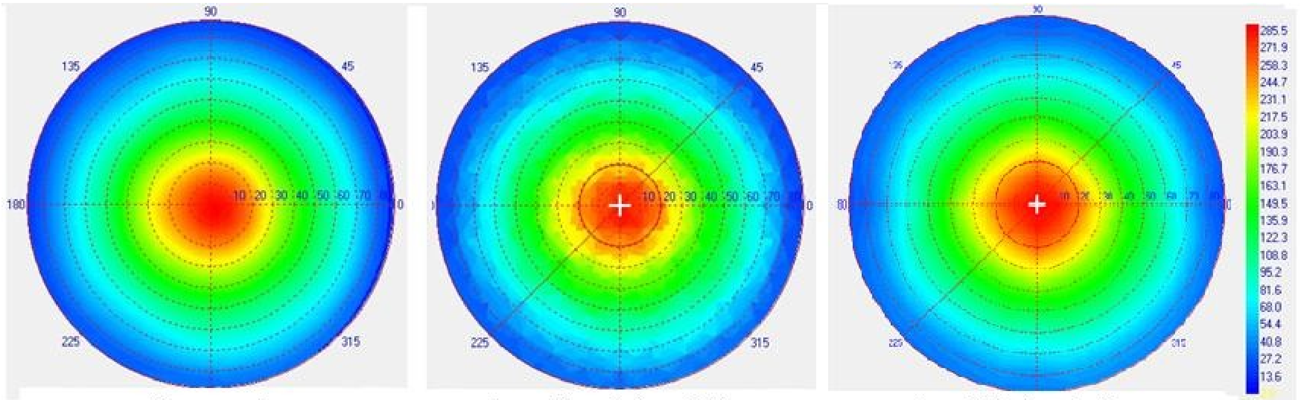


Figure 4: Angular resolution and number of leaf triangles as a function of the sphere decomposition level



Measured   **Level 3 no interpolation**   **Level 3 interpolation**

Figure 5: White state luminance emission as measured (left), reconstructed with subdivision level 3 without interpolation (center) and with barycentric interpolation (right)

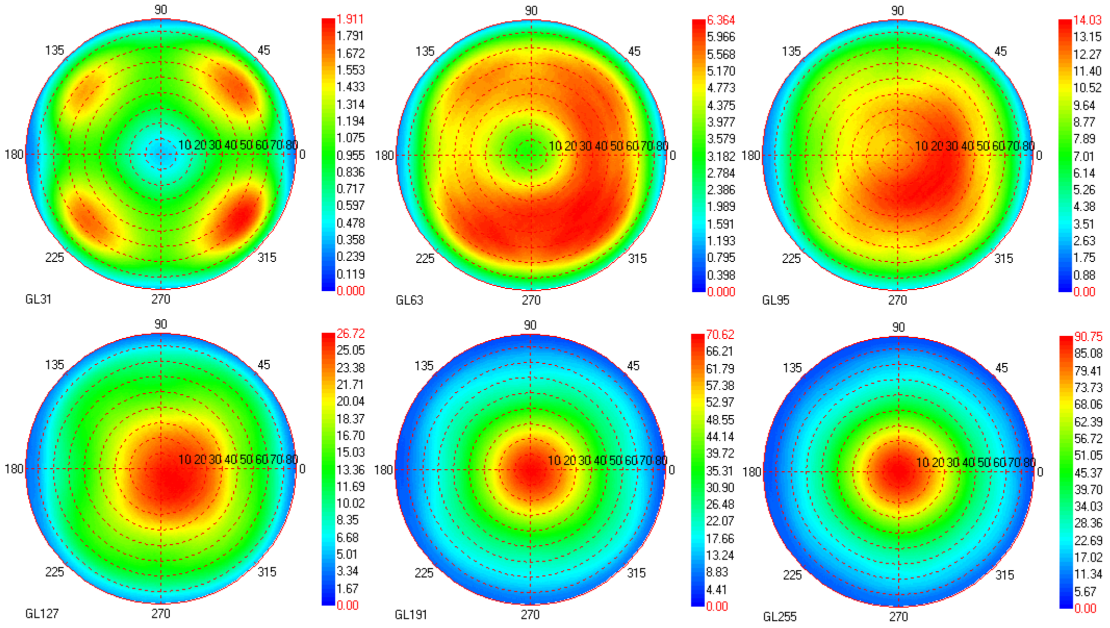


Figure 6: Viewing angle luminance measurements at six different levels for the red state.

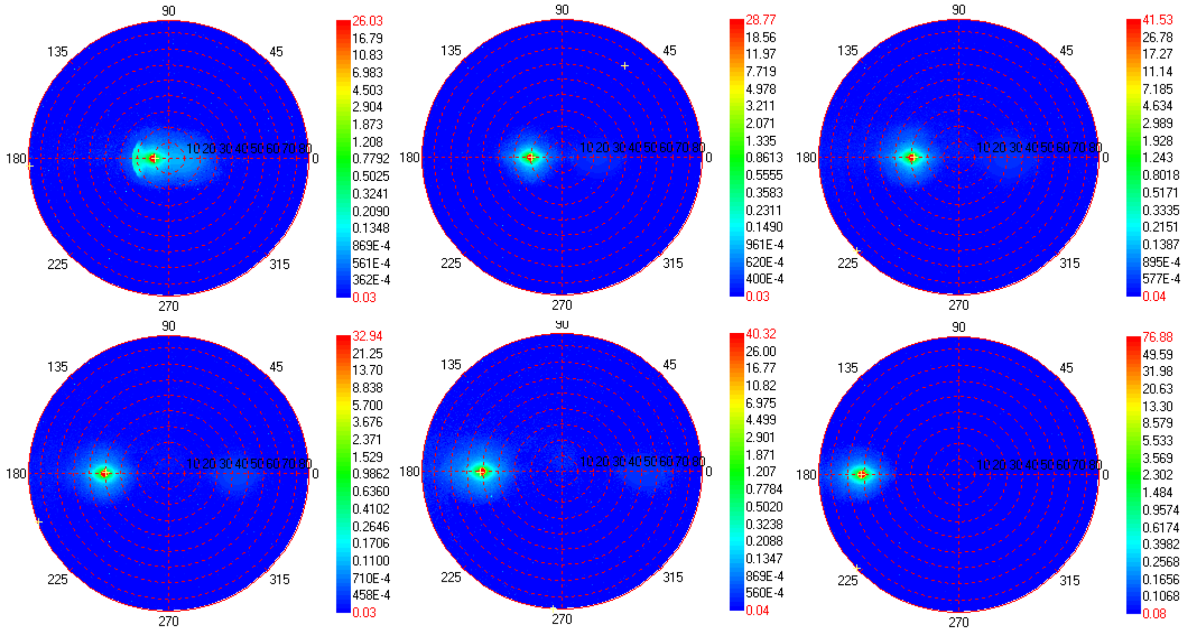


Figure 7: BRDF measured on a display surface at 550nm for six different incidence angles (10, 20, 30, 40, 50 and 60°)

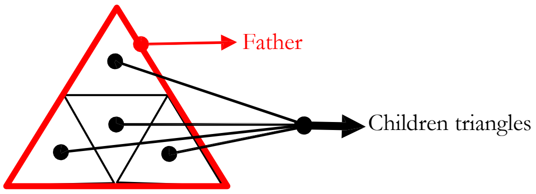


Figure 8: Subdivision of the triangles

Figure 9: Hemispherical subdivision at level 0, 1 and 2