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Simulations of impulse response for diffuse indoor wireless channels

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Abstract – Calculating channel impulse response is important in all forms of communications. In the case of diffuse infrared wireless networks channel response varies abruptly with changes in receiver/emitter position so the development of tools capable of estimating this response in any circumstances is even more important. Nowadays John Barry's spatial discretisation algorithm is the most frequently used method of calculus [1]. In this paper we show a way to improve the algorithm's speed and a way to account for the influence of both diffuse and specular radiation.

Keywords: **diffuse infrared, indoor free space communications, wireless channel, pulse response**

I. INTRODUCTION

Radio wireless dominates the market nowadays with a variety of systems such as WiFi, Bluetooth, UWB. However optical infrared, especially indoor, remains very practical in certain applications, either as an alternative to radio or as a complement. Optical wireless users enjoy better privacy since, contrary to microwaves, light does not pass through walls. Optical security is the only medical issue that these networks pose, unlike microwave, which rise more and more concern. Electromagnetic compatibility is no longer a problem, making indoor infrared communications viable even in such environments as hospitals.

Research is led nowadays to increase bit rate in optical wireless networks and to find multiple access solutions.

In 1993 John Barry published a method of calculating indoor channel impulse response by dividing the total surface of the room in elementary surfaces and calculating the respective *k* order response for each of these surfaces as a function of the *k-1* responses of all surfaces. Because of the recursive calculus the result is slow and several optimizations have been brought since its invention [2]. While developing a link simulator we have brought our own contribution (chapter III).

To this day impulse response simulations have used purely diffusive environments, which basically means that the incidence angle is never taken into account. In other words not only is the original source Lambertian but so are all the secondary sources – the walls or furniture. This isn't usually a big approximation since many materials act as purely diffusive reflectors. However it is to see what happens if we do take in account specular radiation as well (paragraph IV).

II. THE ALGORITHM

We suppose that a source S emits a unit pulse at time 0 inside a rectangular room where we have one receiver R. In a first approach we suppose that the environment is purely diffusive, governed by Lambert's law:

$$R_S(\phi) = \frac{n+1}{2\pi} P_S \cdot \cos^n(\phi) \qquad \phi \in [-\pi/2, \pi/2] \tag{1}$$

Part of the light arriving on the receiver will come directly from the source (if a direct pass exists). This is the 0 order impulse response.

$$h^0(t;S,R) \approx \frac{n+1}{2\pi} \cos^n(\phi) d\Omega \cdot rect(\phi / FOV) \cdot \delta(t - R/c) \tag{2}$$

The rest will be reflected on the walls of the room so that the total impulse response will be:

$$h(t;S,R) = \sum_{k=0}^{\infty} h^k(t;S,R) \tag{3}$$

where each term h^k represents the pulse response given by the light arriving on the receiver after a number of k bounces.

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$$h^{(k)}(t;S,R)=$$

$$=\int_S h^{(0)}(t;S,\{r,n,FOV,dr^2\})\otimes h^{(k-1)}(t;\{r,n,1\},R) \quad (4)$$

But, following John Barry's method, if we consider the walls discrete, made up of N indivisible elementary surfaces the function becomes:

$$h^{(k)}(t;S,R)\approx\sum h^{(0)}(t;S,\varepsilon_i)\otimes h^{(k-1)}(t;\varepsilon_i,R) \quad (5)$$

and more explicitly:

$$h^{(k)}(t;S,R)\approx\frac{n+1}{2\pi}\cdot\sum_{i=1}^{N}\left(\frac{\rho_r\cos^n(\phi)\cos(\theta)}{d^2}\cdot rect(\phi/FOV)\cdot h^{(k-1)}(t-d/c;\{r,n,1\},R)\Delta A\right) \quad (6)$$

where ΔA is the area of the receiver and the rectangular function is defined above.

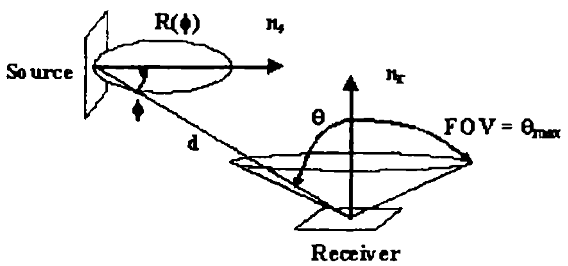


Figure 1 Source – Receiver configuration

A program has been written implementing this algorithm. It calculates h^k for a given number of parameters. In the figure bellow we show our results for the standard 5/5/3 room used by most authors with the typical parameters [1]. A k=3 maximum reflection order was taken into consideration.

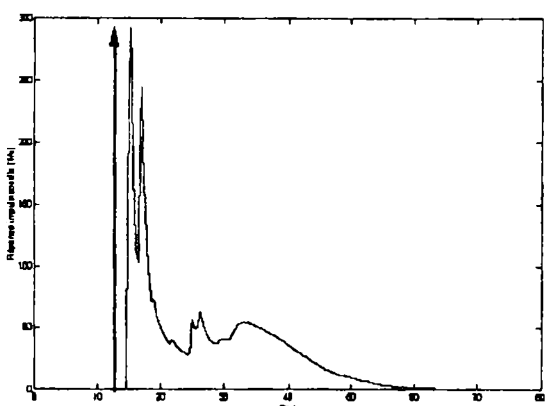


Figure 2 Standard room pulse response

III. OPTIMIZATIONS

The enormous volume of calculus renders spatial numerical algorithms slow even on powerful machines so any amelioration in speed is more than welcome. We have considered the two possible solutions proposed in [1]: a direct implementation of (4) and an implementation using look up tables. The first is more suitable for inferior *k* where high resolution is needed. The second works better for the superior reflection orders where a high spatial resolution (high N) is needed.

Certain aspects are to be considered during the implementation. Computing the vector's absolute value not by using the Euclidian distance should do for example calculating the distance between a source-receiver pair, which is needed to calculate the delay.

But we can gain more in terms of speed if wee consider physical reality carefully. Light undergoing *k* bounces between point A and point B will always travel slower than light undergoing *k*-1 bounces under the same points A and B. Therefore the first non-zero sample that appears when calculating h^k will appear after the first non-zero sample h^{k-1}. It therefore becomes useless to calculate a certain number of points as shown in figure 2.

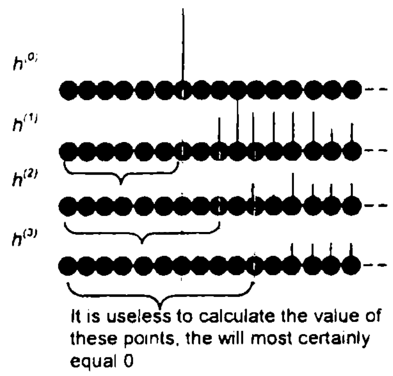


Figure 3 Optimized solution

IV. RESULTATS USING PHONG'S LAW

As we have shown in Chapter I we have considered a purely diffusive reflection model as used in previous publications. In reality however a small part of the total radiation is specular. It is quite hard to model the complete phenomenon taking into account both specular and diffusive radiation.

In image processing, however, Bui Tong Phong proposed in 1975 an empirical reflection model, which served to generate computer images, this seemed more plausible to the human eye [4]. The model is realized by taking into account the specular radiation that becomes significant when dealing with smooth surfaces.

A variant of Phong's law was also used by Yang and Lu to calculate infrared illumination diagrams in a room, [4].

We have used a similar variant to compute impulse response. The Lambert's law (1) is replaced by Phong's law:

$$R_S(\phi,\theta)=\frac{1}{\pi}[r_d\cos(\phi)-(1-r_d)\cos^m(\phi-\theta)]$$
$$\phi\in[-\pi/2,\pi/2] \qquad (8)$$
$$\theta\in[-\pi/2,\pi/2]$$

where r_d represents a coefficient indicating the percentage of diffuse radiation and m is a parameter describing specular radiation. For r_d = 1 Phong's law becomes a first order Lambert's law

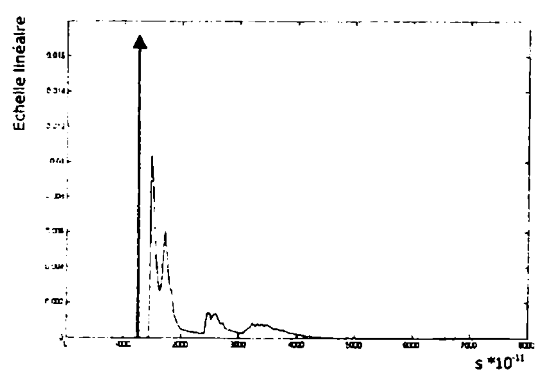
The equations we obtain for h^0 and h^k are:

$$h^0(t;S,R)\approx\frac{1}{\pi}[r_d\cos(\phi)-(1-r_d)\cos^m(\phi-\theta)]d\Omega \cdot rect(\phi/FOV)\cdot\delta(t-d/c) \qquad (9)$$

$$h^{(k)}(t;S,R)\approx \frac{1}{\pi}\sum\frac{\rho_r[r_d\cos(\phi)-(1-r_d)\cos^m(\phi-\theta)]\cos(\theta)}{d^2}\cdot rect(\phi/FOV)\cdot h^{(k-1)}(t-d/c;\{r,n,1\},R)\Delta A \qquad (10)$$

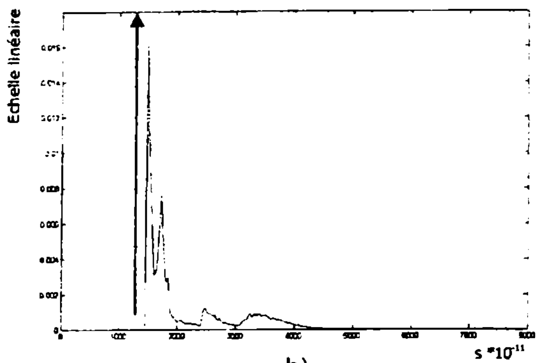
In figure 3 we show the differences the results obtained when using Phong's and Lambert's law. The parameters of the source receiver and channel are listed in table 1.

LAMBERT



a)

PHONG



b)

Figure 3 Lambert's law results (a) vs. Phong's law results (b)

Wall	Material	Reflection coefficient	1st Phong coefficient	2nd Phong coefficient
Ceiling	Wall paint	0.184	1	1
Floor	Wooden boards	0.128	0.6	6
West	Brown shelves	0.0884	0.5	2.8
East, North, South	Glass	0.0625	0.001	13

Table 1

V. CONCLUSIONS

Wireless infrared communications can replace wireless radio, sometimes with better results and lower costs. It is however important to observe that in the case of non-directive indoor networks only a very small fraction of the total radiation emitted by the source actually arrives on the receiver. For every Watt emitted less than a μWatt is received in most cases. This fact and combinded with strict eye safety power limitations are in fact the main problem.

Under these circumstances it is even more important to conduct thorough research to a optimized model of the transmission channel.

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