Introduction

Time-Of-Flight imaging is a very common technique to obtain 3D images, giving information about the time of the pulse and its energy. However, in turbid media, such as the ocean or with the presence of fog, TOF method doesn’t give neither a correct radiometric information nor of its raytrace. The impending creation of a 3D LIDAR imaging camera working in these types of media requires the presence of a more accurate model that keeps diffusion in mind and has a temporal dependence.

In turbid media, such as the ocean, the images obtained are strongly blurred (see Figure 1), due to their scattering condition, which make the rays change many times their direction (Figure 2). The goal of this project is to develop and validate a new method that has a temporal dependence and could be valid in strong scattering conditions, simulating the ones that are common in the ocean.

Modelling Diffusion

- Monte Carlo/ Finite Elements: Monte Carlo method is based on the random walks that photons make as they travel through the turbid media. It is the typical approach and it is used in many well-known software programs, such as TracePro. It also gives a high spatial resolution, as well as photometric information. Nevertheless, one of the main disadvantages of the implementation of this model with TracePro, is that it doesn’t give a temporal dependence.

The other method, finite elements does have a temporal dependence. However it is very difficult to implement. Therefore, these two models are not appropriate to this project.

The Diffusion model: The diffusion model is a method that quantifies the photon transport. It treats separately the effects of scattering ($\mu_s$) and absorption ($\mu_a$).

Its validity rests on the fulfillment of the following condition:

$$\mu_a > \frac{1}{\lambda} \left( \frac{\mu_s}{\mu_a} \right)^{\alpha}$$

Which considering that the typical anisotropy factor ($g$) is 0.9, the condition stands as:

$$\mu_s > 100 \mu_a$$

There are three types of light sources that could be used, but in this project, simulating a LIDAR system, the light source will be a short pulse. With this type of source and considering sea water as an infinite, homogeneous turbid media, the photon fluence rate behaves as:

$$\Phi(r,t) = \frac{\mu_a}{\mu_s} \exp \left( -\frac{r^2}{4 \mu_a t} \right)$$

With $\lambda=\mu_s/\mu_a$ and $D(r) = \frac{\mu_a}{3(\mu_s+\mu_a)} r^2$

The advantage of this model is that it fulfills the time dependence condition, and it also gives information about radiometry, fitting with the needs of this project, and being the selected one to implement in this thesis.

Methodology

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Results

A square target of 12.5m x 12.5m is placed at different distances, far from the detector. The water properties are: $\mu_s = 0.07 \text{ m}^{-1}$, $\mu_a = 8 \text{ m}^{-1}$ and $g = 0.9$.

Taking the maximum value of the photon fluence rate we have a linear relation between the measured distance to the target and its real value, which, for all the pixels is:

$$d_{\text{real}} = \frac{2.86 \times d_{\text{meas}}}{4.673} [\text{m}]$$

However, the 3D LIDAR camera system use a threshold value to define the distance measured, which adds an extra delay.

Conclusions

- Monte Carlo method gives only an accurate description of the fluence rate when the number of rays is large (~100000 rays the fluence rate starts to have the proper shape). However, it is very cost-effective, taking too much time to make the simulation.

- Due to this large computation time and the fact that the high spatial resolution of the Monte Carlo model isn’t needed, a simplest and fastest model is required, the Diffusion Model.

- Applying the diffusion model in strong scattering conditions, we can see a huge delay, usually more than twice the time obtained by I=V/c. The reason of this delay is that, as it is seen in figure 1A, photons travel much more distance before arriving to the target.

- Looking at both relations between the measured distance and its real value we find that the diffusion Model isn’t accurate in short distances, when the target is close to the source, as the relation will give a negative distance.

Bibliography