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Enhancing Tissue Depth Imaging

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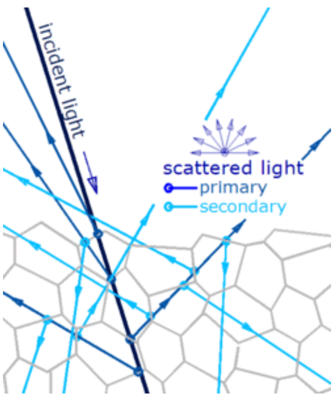
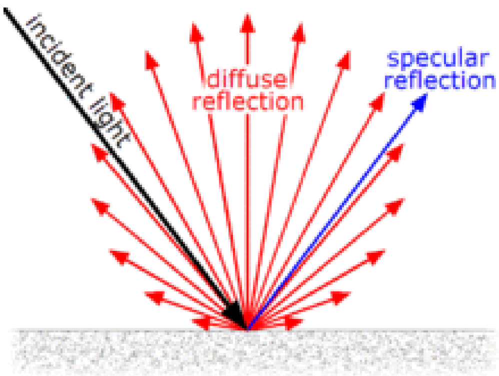
Abstract

The image observed by scattered light involves mainly single event scattering. In a single event scattering, a 180 degrees backward scattering of directional light is automatically coherent. This light can be separated from non-coherent scattered light by interferometric methods. Therefore directional backscattered light may be utilized for tissue imaging of enhanced depth. The same argument is true also for zero degrees scattered directional light, that is, with transmitted light. So that imaging of thicker tissue samples is possible.

Background

Non-specular scattered light from bodies and surfaces is considered diffused [1]. The light illuminating a body is scattered many times before it is reflected to an observer. A randomly multi scattered light obeys Lambert's cosine law, which states that the scattering is maximal in the direction perpendicular to the surface, and it falls to zero by the cosine function, together with the inclination angle to the surface [2]. A surface which obeys Lambert's cosine law is called a Lambertian scatterer [3].





Diffused light scattering [1] and Lambert's cosine law [2].

The full moon is the most prominent object in the night sky. The full moon image has two significant properties: The image is uniform [4], and the light intensity of, 180 degree back scattered light, is enhanced about 50% compared to a non-back scattered light. Even a deviation of 5 degrees from the backward direction will eliminate this enhancement. The enhancement is called the opposition effect [5, 6]. Since the moon image does not fulfill the Lambertian cosine law, it is considered a non Lambertian scatterer.

There is a rich literature that deal with the moon uniformity, and it all involves properties of the moon surface [7]. However, there are many celestial objects with similar configuration, and with solid, liquid and gas surfaces. They all show a similar uniformity, e.g., the earth, all the other planets and all their moons. Therefore a theory of the uniformity should have a more general basis.

The enhanced back scattering, the opposition effect, is considered in the literature a result of coherent back scattering [8]. But again, the coherency is discussed in terms of surface properties, though the effect is observed in many different surfaces, both celestial and terrestrial. In addition, the literature does not explain why the effect is observed only in solids and not in liquids and gases.

The purpose of the following discussion is to show that the scattering is mainly a single event effect.

Discussion

Theories of light scattering are discussed only for the moon case but the discussion should be more general and applicable to other systems [7].

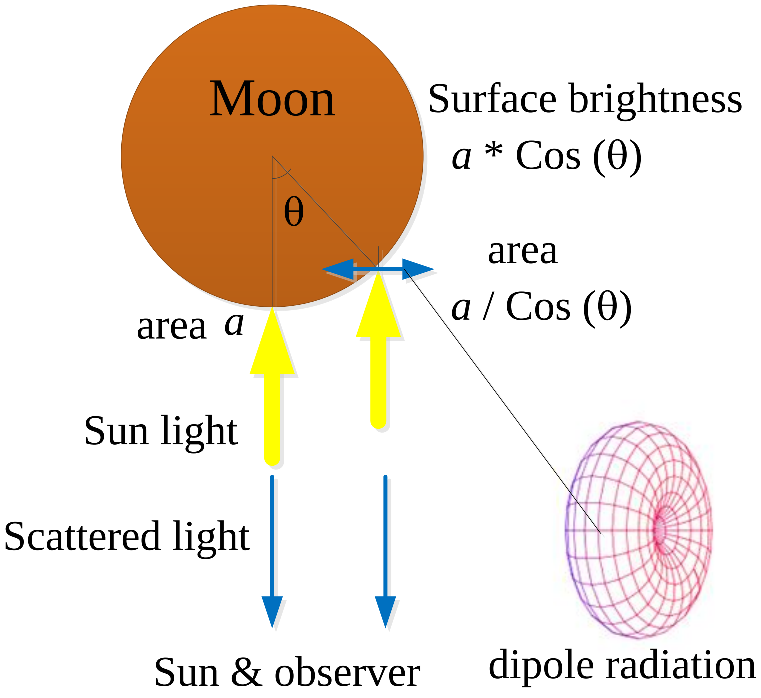
When an electromagnetic wave advances in a medium it polarizes its matter, and each polarized dipole is a source of electromagnetic wave. The effect of all the dipoles is calculated, for example, by vector addition of their electric fields. Each dipole has a different phase that depends on its position, and if the material is uniform these fields cancel each other in all the directions except the forward direction, where the effect is refraction.

Scattering comes from non-uniform fluctuations of material density, and then scattered waves may advance in any direction. The intensity of scattered light is the sum of the intensities of the scattering centers and it does not depend on the phases of the scattering dipoles.

The purpose of this discussion is to indicate that the uniformity of the moon image is a direct outcome of single light scattering. Further mechanisms or models are not necessary. The moon surface is Lambertian after all in the sense that the scattering is random, although it does not obey Lambert cosine law [7].

Consider an imaginary line between the sun and the earth, or between the sun and the moon, and a unit cross section area *a* on a plane perpendicular to that line.

A Figure shows an observer on the earth looking at night at the full moon, while the sun is behind his back.



A Figure: Relative configuration of the sun, the moon and an observer on the earth.

> Sunlight brightness $a * \text{Cos}(\theta)$ on the moon illuminates the area a / $\text{Cos}(\theta)$ through a. The sun light polarizes the moon surface perpendicular to the light direction. The moon dipoles scatter maximum light back to the sun, and back to an observer on the earth.
>
> θ is the angle between a line from the moon center to an observer on the earth, and a line between the moon center and any point on its surface.

It is beneficial to go a little deeper into the scattering mechanism. Sunlight that falls on the moon, induces dipole charge oscillations on its face. Each such a dipole is a source of light, and the overall scattered light is the combined effect of all the dipoles.

Each dipole oscillates in the electric field direction of the coming sunlight, that is, in a plane perpendicular to the light direction, and the maximal emission of a dipole is perpendicular to its direction of oscillation, that is, back to the sun.

Therefore, the mean equivalent moonlight will also be directed back to the sun, and in full moon also to an observer on the earth. It will not be perpendicular to the moon surface.

Considering the fading sunlight on the moon surface, the back scattered moonlight will be proportional then to:

$$(a / \text{Cos}(\theta)) * \text{Cos}(\theta),$$

Observer on earth will see a uniform full moon.

In summary, the mean back scattering from the full moon is directed back to the sun because the scattering dipoles on the moon oscillate in a plane perpendicular to the coming sunlight. Any calculation that does not take the direction of the polarizing dipoles into account will not be correct.

In the calculation of Lambert's cosine law there is a hidden assumption that the scattering dipoles oscillate in all random directions in space. This is not the case with the moon, and probably with other examples. In the case of single scattering, the scattering dipoles conserve the polarization plane of the coming light and lead to uniform surface image.

In multiple scattering the dipoles lose this plane of oscillation, then scattered light should obey Lambert cosine law. However, since the dipoles lose their direction plane, and therefore also their defined phases, there is no way that the scattering will be coherent. In addition, as a process involves more and more scattering steps, the probability for it will come down, and the first single scattering will be dominant.

Conclusions

The full moon image tells us that single scattering mechanism is responsible for the full moon uniformity. This conclusion is more general and compliant to most images of scattered light, that is, nearly everything that we observe around us.

The dipoles, which generate the scattered light in a single event, are all coherent since they are directly induced by the illuminating radiation. In the case of 180 degree back scattering, the intensities of the light scattering centers add together and enhance the light signal.

In multiple light scattering the coherence is lost. In a mixed signal the coherent single backscattered light can be separated from incoherent multiple scattered light by interferometric methods [8].

The penetration depth, of an image of a tissue, can be enhanced in a system configuration of back light scattering and interferometric mixing that reduces the incoherent background.

In a similar way, interferometric mixing in a space vehicle, of back light from a celestial object with direct signal of sun light, will increase the observation distance of the object.

References

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On the web: March 2020

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Moral of the story:

The scattered light is considered in the literature as a diffusive light, light that passed a number of scattering events before it left the scattering material. Diffusely scattered light must obey Lambert's Cosine scattering law. In the case of unidirectional light scattered backward from a surface of a sphere, the meaning is maximum scattering intensity in the middle of the sphere surface, and a decline to zero toward the periphery by the cosine law.

The full moon looks uniform, people continue to assume that the light is diffusely scattered from it, and make double saltas and backward flick-flacks in order to try to explain the uniformity, in my opinion, without success.

More than that. The nearly uniform sphere image, is common to all the planets and their moons, including the earth as observed from the moon. Out of thousands upon thousands true photos, there is no single true photo that obeys Lambert's Cosine law. The only photos that do obey the law are rendered photos, photos that are at least partly simulated. Rendering: If the theory does not comply with reality we'll change the reality.

Contrary to all that, if the scattering is assumed to be mainly a single event, then all the scattering dipoles are directly stimulated by the light radiation on the illuminated scattering material. Then scattering by them must be coherent, and then the full moon and all the other illuminated bodies, with similar illumination geometry, must be uniform, at least approximately. The full moon tells us that single event scattering is dominant. Maybe with small corrections of multiple scattering.

Why is the single event dominant? It seems that the effect is geometrical and statistical. If we consider one event scattering, two event scattering, multiple event scattering, then the event probability will decline with an increasing number of scatterings. The single event has a probability of at least 50% and it is the strongest event. Assume that someone can make more accurate statistical calculation.

Nearly all the background landscape that surrounds us is a singly scattered light. A true diffusely scattered light is rather rare.

In summary, the full moon tells us how to remove undesirable incoherent stray light from coherent scattered light, for example, in optical absorbance measurements.

Added, April 2020

Multiple scattering:

Each scattering center is a source of radiation in all directions. Radiation scattered in a random direction loses its coherence except the forward direction where it is coherent with the stimulating radiation. Therefore, a multiple forward scattered radiation is coherent and will contribute to the forward signal. In other directions the radiation goes out of phase of the stimulating radiation and will be part of the spatial background noise.

Forward scattering is dominant in solids (Mie scattering) where the size of the scattering center is large compared to the radiation wavelength. In liquids and gases the size of the scattering center is small compared to the wavelength, the scattering is isotropic (Rayleigh scattering), and the effect is less prominent.

Added, May 2020.