Holographic Metrology and Basic Physics

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Abstract. A short pulse of light is emitted from one point followed by a short observation from another point separated in space and time from the first. Even if space is full of scattering particles no sphere of expanding light is seen from outside by the observer, instead he finds himself inside an ellipsoid of light. We use this ellipsoid for measurement and in a graphic way to explain and evaluate optical resolution, gated viewing, radar, holography, 3-D interferometry and Special Relativity. In the later case the Lorentz Contraction together with the Time Dilation are explained as results of the eccentricity of the measuring ellipsoid, caused by its velocity. Finally, the extremely thin ellipsoid of the very first light appears as a beam aimed directly at the observer which might explain the wave or ray duality of light and entanglement.

Keywords: Gated viewing, ultrashort pulses, holography, optical resolution, interferometry, relativity, duality of light

1. Appearance of the sphere of observation

In a space filled by scattering particles (C) a point source (A) emits a short pulse of light of the length of 3mm (c:a 10^{-11} sec). After the time t_0 pulse has expanded into a sphere of two meters radius. (1 meter is the distance light travels in 1/299,792,458 of a second.). It is now photographed by camera (B) with such a short exposure time that it freezes the motion of the light. Recorded will be only those particles or those objects that at that moment are illuminated by the thin spherical shell of light. If the distance A-B is zero, a sphere with a radius of only one meter is recorded, because the light has to go the distance A-C-B where C is an illuminated point. This sphere we name “the sphere of information”. If the distance A-B is nonzero, but less than two meters the recording will be that of an ellipsoid with (A) and (B) as focal points because light still has to travel the two meter distance A-C-B. If A-B is greater than two meter nothing will be recorded because the sphere can not be seen from outside. Finally, if A-B is exactly two meter the ellipsoid has such high eccentricity that it has become just a line from (A) to (B). (Fig.1).Could this deformation in absurdum also be used to visualize the apparent concentration of the sphere into beams of energy?
Thus, we have shown that the sphere of information changes from a sphere to an ellipsoid to a line solely because of the existence and the position of an observer (Fig.2).

Usually these changes are of no importance when light is used for measurement such as classic interferometry, RADAR, LIDAR where A-B is zero. However, for holographic interferometry\(^1\) and for Special Relativity the situation is different because A-B are separated by static distance respective by velocity. Thus, if intersections of the ellipsoids are used for measurements of object deformations the same correction factor has to be introduced in holographic interferometry and in special relativity as shown later on. This correction can be visualised by the holodiagram (Fig.6).

The sphere of information transformed into ellipsoid:

\[
\frac{b}{a} = \frac{b}{ct_0} = \cos \alpha = \frac{1}{k} = \sqrt{1 - \frac{f^2}{c^2t_0^2}}
\]

2. Moiré analogy

In Fig.3 we see the moiré analogy to the ellipses\(^3\). Two sets of circles are added to each other, the centre of one represents a light source (A) the other (B) an observer. The moiré pattern formed by the two sets of circles consists of one set of ellipses and one set of hyperbolas, which are normal to each other. The ellipses are stationary if one set of circles is moving outwards (source) while the other is moving inwards (observer) at the same velocity. The ellipses also represents the interferometric resolution of holographic interferometry and CD represents e.g. the resolution of a lens.

\[
EF = 0.5 \lambda \cos \alpha; \quad CD = 0.5 \lambda \sin \alpha
\]

One of the rhombs of Fig.3. Where EF represents resolution of holographic interferometry and CD represents e.g. the resolution of a lens.
measuring sensitivity e.g in holographic interferometry where the hyperbolas represent sensitivity direction. If both circles move outwards or inwards the hyperbola represent stationary interference fringes eg visualizing the resolution of a lens having A-B as diameter.

If A-B is the diameter of a lens (D) the separation of the hyperbolas represents the resolution limit of that lens. If A-B instead represents the diameter of an object the separation of the hyperbolas represent the lens diameter needed to resolve that object. From Fig.3 we see that the interferometric sensitivity is maximal \((\lambda/2)\) where the ellipsoids are closest together, which is along the axis outside A-B and at infinite distances. The transversal sensitivity is maximal where the hyperboloids are closest, which is closest to the lens while it is zero at infinite distances. These are some of the reasons why interferometry is useful for long distances, while microscopes are used for as short distances as possible.

The hyperbolas also represent the information carries in holographic recordings (as described by Tung H. Jeong).

3. Holographic interferometry

Let (A) and (B) be sources of coherent light that are phase locked by simply arriving from the same laser. In that case stationary interference fringes are projected corresponding to the hyperbolas of Fig.3. The separation \(d_{\text{hyp}}\) of these fringes is \(d_{\text{hyp}} = \lambda/2\sin \alpha\). The ellipses are formed when (A) is the source of coherent light while (B) is a point of observation made phase locked to (A) eg being observed through a hologram plate that was exposed and reconstructed by light arriving from (A). The separation of these fringes used for holographic interferometry are \(d_{\text{ellips}} = \lambda/2\cos \alpha\).

The ellipsoids, which we refer to as “ellipsoid of observation” can be recorded and studied using a method named “light-in-flight recording by holography”. A hologram is recorded when two beams of coherent light (the object beam and the reference beam) intersect at the holographic plate. Interference fringes can be formed on this only if the two components illuminate the plate at the same time. In Fig. 5 one single picosecond pulse is emitted by (A) and a mirror (C) reflects the pulse to the holographic plate (B). Thus, the reference beam works as a picosecond shutter that moves over the hologram plate with a velocity higher than light, recording on each point of the plate only objects that are situated on the ellipse that intersects the reference mirror.

If we let the steps by which we increase the \(c(t_0)\) of Fig.2 be very small, e.g. only the wavelength of light \((\lambda)\), we will find that (b) increases by \(\lambda/2\cos \alpha\). The result is that the wavelength along the y-axis appears to be increased to \(1/2\cos \alpha = k\). An ordinary example of such apparent increase of \(\lambda\) is that a rough surface appears more mirror-like the more oblique is the observation. In interferometric measurements, classic or holographic, the number of interference fringes has to be multiplied by 0.5 \(k\lambda\) to find the displacement causing the fringes (Fig.3). If we do not make any corrections, measured distances appear shorter where the separation is larger (Fig.3).
The "holodiagram" (Fig.6) is based on the ellipsoids of Fig.3 and constructed to evaluate the interference fringes in holographic interferometry. The focalpoint (A) is the point source of light, while focalpoint (B) is the point of observation, behind the holographic plate. In double exposed holography the deformation (d) at any point (C) is calculated: \( d = n \frac{k}{0.5\lambda} \) where (n) is the number of interference fringes, (k) is \( 1/\cos \alpha \) where \( \alpha \) is half the angle ACB. The angle \( \alpha \) is also constant along circular arcs through (A), (B) and (C). The distance A-C-B is \( ct \) where (c) is the velocity of light and (t) is time. The interferometric sensitivity vector is everywhere perpendicular to the ellipsoids. On the x-axis in between (A) and (B) the k-value is infinite, while outside (A) and (B) it is unity. In Fig.4 we study the k-value at the y-axis.

The calculations made in Fig.2 reveals that the k-value used in holographic interferometry (eq. 1) is strikingly similar to equations in Special Relativity which was one of the facts that inspired to use the ellipsoids also in that field:

\[
k = \frac{1}{\cos \alpha} = \frac{a}{b} = \frac{f}{ct_0} = \frac{1}{\sqrt{1 - \frac{f^2}{c^2t_0^2}}} \quad \text{Eq.1}
\]

4. Special relativity

What happens if the separation from (A) to (B) of Fig.2 is dynamic instead of static, if the one who performs the measurement at high velocity passes the object to be measured (C)? At (A) the pulse is emitted and at (B) it is observed. The sphere of observation is transformed into an ellipsoid just as in Fig.2 but in this case the distance (f) is represented by \( vt \).

The elongation of the sphere of observation by \( 1/\cos \alpha \) results in that objects measured with this ellipsoid appears shortened in the direction of velocity by the factor \( \cos \alpha \) (Fig.6). In this way the Lorentz contraction is explained as caused by the elongation of the measuring tool, the sphere into the ellipse (Fig.7). This fact is further confirmed by the fact that our basic measuring tool the Meter is by definition elongated by velocity. Whether the Meter is defined by lines on a ruler, by wavelengths or by \( (ct_0) \) it is...
elongated along the line of velocity by the factor \(1/\cos \alpha\) caused by time dilation. There is however one problem.

![Fig. 8](image)

The velocity elongates the sphere (a) by a factor \(1/\cos \alpha\) to the ellipse (b). This effect is invisible to the observer B who thus measures the object L foreshortened (c) by the factor \(\cos \alpha\).

Dilation \(\gamma\) introduced by Einstein\(^9\) where time is increased by the factor \(1/\cos \alpha\) resulting in that ct and vt are elongated by the same factor so that (b) is no longer influenced by velocity \((v)\). Thus we have by using the holodiagram visualized Einsteins two equations:

\[
\frac{t_v}{t_0} = \frac{1}{\cos \alpha} = k = \frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}},
\]

Eq. 2

\[
\frac{L_v}{L_0} = \frac{b}{a} = \cos \alpha = \frac{1}{k} = \frac{1}{\sqrt{1 - \left(\frac{v^2}{c^2}\right)\left(\frac{t_0}{t_v}\right)^2}} = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} = \frac{1}{\gamma},
\]

Eq. 3

Going back to the rhomb of the holodiagram (Fig.4) we find that Eq.2 is represented by the diagonal \((EF)\) if the fixed distance \(A-B\) is exchanged by the increasing distance \(vt\), resulting in all ellipses of the original holodiagram having the same eccentricity.

5. Conclusion and consequences

What is light? What does it look like? Is it made up of waves or of particles? Why is it so that when the sphere of light expands and its energy is diluted, it still can be absorbed by atoms as if its energy was concentrated to beams with needle-point accuracy. We explained this fact with our alternative graphic derivation of relativity using the deformation of spheres into ellipsoids. Thus, we have shown that just only the existence of an observer causes the ellipsoid and that the position and velocity of this observer influences its eccentricity. The extremely thin ellipsoid of the very first light appears as a beam aimed directly at the observer, which might explain the duality of light which sometimes appears in the form of waves sometimes as rays. When the original sphere consisted of
the energy of one single photon the first light arrives in the form of a ray and if it is absorbed no collapse of the sphere is needed for explanation.

The Sphere of Observation is also a sphere of apparent Simultaneity when observed from its center. When this sphere is elongated the loci of apparent simultaneity will be on the surface of the ellipsoid, which when the velocity approaches that of light becomes a line of stationary time. The fact that (A) and (B) are the focal points of the same ellipsoid results in that they share the same apparent Sphere of Observation, and the same point of time which probably could explain some of the spooky effects of entanglement where information appears to pass from (A) to (B) instantaneously.

A velocity higher than light is however forbidden by Einstein who states that nothing can travel faster than light. Phenomena connected to entanglement appear at first to be exceptions. My explanation is that in those cases the information has no mass or energy. It is not transported by any carrier. Such “naked” information can not be reconstructed until energy is later sent in the form of correlation using ordinary information at the velocity of light. In entanglement we see that even if the naked information can not be detected directly because its lack of energy it still can influence what happens at random, because in Quantum Physics there is by definition no energy difference between two states that happen randomly.

The collapse of the sphere can be explained in an alternative way by using the four-dimensions of relativity as described by the Minkowski cones, which we have modified by moving one cone in relation to the other along x- and t-axis (Fig.10). The illumination cone represents the expanding sphere with its centre at (A). The observation cone represents the sphere contracting towards the point of observation (B). Different intersections of the cones produce all the ellipses (ellipsoids) of Fig.1. When the two cones just touch each other the tangential line represents the concentrated beam of the “first light”. Finally, the null result of the Michelson Morley experiment is with our method confirmed by the fact that the light path ct = A-C-B is constant independent wherever on the ellipsoidal surface is positioned. Fig 2 also illustrates the impossibility of a velocity (v) greater than that of light (c).

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