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RESEARCH ARTICLE

Exploiting a Built-In Simultaneity: Perhaps, the Simplest Way to Show that the One-Way Speed of Light is Measurable in Principle

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ABSTRACT

We consider a physical system composed of a rod of length AB $= L$ rotating uniformly. Two points on the rod cross-sections at A and B are connected in a way that reflects the simultaneity built-in into the system. This preset simultaneity can be exploited to synchronize two distant clocks, one at A and the other at B, with an internal procedure that, in principle, may differ from Einstein synchronization. The natural built-in simultaneity can be used for testing the one-way light speed and Lorentz invariance.
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Keywords: Conservation of simultaneity, Lorentz invariance, one-way speed of light, relative simultaneity.

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1. Introduction

The stimulating theme of how to measure the one-way speed of light has been widely discussed in literature because it touches on fundamental aspects of relativity theory. However, in most textbooks of special relativity, the related fundamental subject of clock synchronization is not discussed, and the readers often rely on articles published in didactic journals dealing with this and related topics. The concept of simultaneity is present in all areas of physics. According to standard special relativity (SR) the simultaneity of two events occurring at the locations A and B, can be revealed by means of two clocks synchronized with Einstein synchronization procedure. With his procedure, Einstein assumes that the one-way light speed coincides with the average round-trip light speed $c = 2L/T$, where T is the time interval measured by clock A for the light round-trip from A to B and back to A. Then, Einstein synchronization consists of setting the reading of clock B at $t = L/c$ when the light ray sent from A reaches B. Epistemologists and physicists [1]–[6] criticized Einstein synchronization procedure, pointing out that, since the one-way speed from A to B can be different from the return speed from B to A, Einstein synchronization leaves undetermined and arbitrary (conventional) the one-way light speed.

In line with the conventionality of the one-way light speed [6], in classical physics instantaneous action at distance and simultaneity are considered to be conventional and indeterminable. According to Mansouri and Sexl [6], internal clock synchronization procedures, such as clock transport from clock A to clock B, turn out to be equivalent to Einstein's. Hence, unless we find a synchronization procedure different from Einstein's, it seems to be impossible to discriminate relative from absolute simultaneity.

The purpose of this article is to introduce a procedure for the synchronization of distant clocks that is naturally built-in into the physical system. If theoretically viable, the "natural" built-in simultaneity can, at least in principle, be used to test the one-way light speed invariance and the velocity of the so-called preferred frame where empty space is isotropic.

2. A Physical System with a Built-in Simultaneity

There are various approaches and attempts to measure the one-way light speed, and we cite here, just as examples, the works of Greaves *et al*. [7] and Spavieri *et al*. [8]–[10]. One of the criticisms made by physicists to some of the approaches presented in literature, is that what is measurable, or has been measured, is the average round-trip light speed c and not the one-way speed. This seems to be the case for the interesting work of Greaves *et al*. [7] according to the comment made by Finkelstein [11], who, citing Reichenbach [2], presents arguments suggesting that the mentioned experiment actually measures the average round-trip light speed c, not the one-way light speed. It would be interesting to consider the arguments of Greaves *et al*. in the conventionalist context of Mansouri and Sexl [6].

Taking into account the issue of clock synchronization and in line with the results of Spavieri *et al*. [8]–[10], in the present approach we adopt a synchronization procedure, which a priori is not equivalent to Einstein's. Let us then consider a rod AB of rest length L and radius $r << L$ stationary in the inertial reference frame S′ with its longitudinal axis parallel to the x' axis. On the circular cross-section at A, let O_A be the center and A^* the point on the circumference with $r = y'_A = O_A A^*$ parallel to the y' axis. When the rod is at rest and, in the absence of external forces, there are no torsional stresses along the rod, on the cross-section at B we may easily spot the point B^* on the circumference with $r = y'_B = O_B B^*$ parallel to the y' axis. Then, the line $A^*{-}B^*$ will be parallel to the x' and the rod axes. After an external rotational impulse has been applied to the rod, which eventually reaches a steady-state uniform rotational motion about its principal axis, we may assume that every point of the rod possesses the same uniform angular velocity ω'_0 and there are no torsional stresses along its length L. Thus, if no permanent deformation has been applied to the rod while reaching the final uniform rotational motion, possible elastic distortions of dynamic origin along the rod have disappeared. Since, due to the cylindrical symmetry, there is physical uniformity along the x' axial direction, in the absence of external torques and internal torsional stresses, the phases (angular positions) of the two uniformly rotating cross-sections, A and B, have not been advanced or delayed. Consequently, all the points along the line $A^*{-}B^*$, initially in phase when the rod is not rotating, will be in phase when in steady-state rotational motion with the line $A^*{-}B^*$ still parallel to the x' axis.

For this physical system, if the radius $O_A A^*$ is aligned with y' in frame S′, even the radius $O_B B^*$ is aligned with y' at the same instant. In other words, the system has a natural built-in simultaneity with reference to the two events $E_A(x'_A = 0, y'_A = r, z'_A = 0, t' = 0)$ and $E_B(x'_B = L, y'_B = r, z'_B = 0, t' = 0)$ representing the two rotating points A^* and B^* intersecting the y' axis at $t' = 0$. This natural, built-in simultaneity can be used to synchronize two spatially separated clocks, one at A and the other at B, by setting at zero clock A and B when, simultaneously, the points A^* and B^* cross the y' axis.

For the case of the synchronization procedure by means of clock transport from A to B, or from B to A, the information about synchronization carried by the transporting clock, is affected by the clock motion because of the intrinsic effect of time dilation [6]. In the latter case, the two procedures, clock transport and Einstein synchronization, turn out to be equivalent, and the same conclusion is valid for rod translation or analogous procedures [6], [12]. However, our natural synchronization procedure does not require transport of information from A to B, or from B to A. In fact, for the rod in uniform rotational motion, the simultaneity of the two events E_A and E_B is naturally built-in into the system and this preset "natural sync", which is not necessarily equivalent to Einstein's, reflects the instantaneous synchrony of the two points A^* and B^* or any other two points on the line $A^*{-}B^*$.

The conventionality of the speed of light seems to hold only for the case when the light speed from A to B is measured with two spatially separated clocks synchronized arbitrarily with the procedure of Einstein, or equivalent, and with the only restriction that the observable two-way average light speed be c. Nevertheless, there are physical situations where the arbitrariness of synchronization does not hold. One example is given by light propagation on a closed moving contour, as in the Sagnac effects [13]–[15], where no clock synchronization is required because a single clock can be used [16]–[23]. Other examples are mentioned in Refs. [16]–[27]. The arbitrariness of the one-way light speed, claimed by conventionalists [6], [28], [29], ceases to exist if, as is the case for our natural sync, an internal synchronization in principle not equivalent to Einstein's, is adopted.

In order to determine whether the natural sync is linked to relative or absolute simultaneity, we may use it for testing light speed invariance as indicated below.

3. Light Propagation from A to B as Described by Different Relativistic Theories and Coordinate Transformations

Let us suppose that the frame S′ is moving with velocity v relative to the reference frame S where clocks are Einstein-synchronized or, as assumed in the preferred frame theories, space is isotropic and the one-way light speed is c. For the system of Fig. 1 we consider the two different coordinate

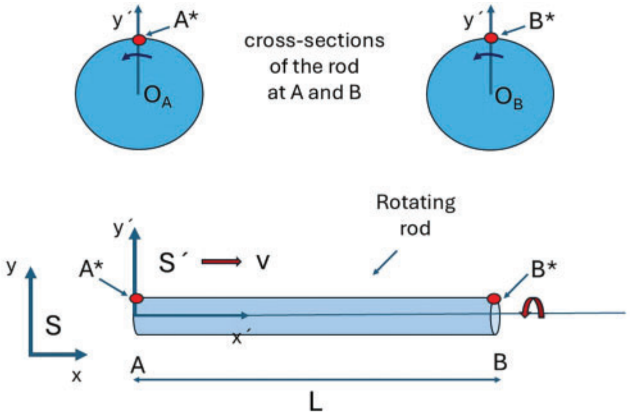

Fig. 1. The rotating rod AB is stationary on frame S′, in motion with velocity v relative to frame S. The points A* and B* on the circumference of the cross-sections are rotating in phase at the same angular velocity. The built-in simultaneity between A* and B* when crossing the y' axis, can be used to synchronize two spatially separated clocks, one at A and the other at B.

transformations described in the Appendix (8), the standard one based on relative simultaneity (LT) and the one denoted as the LTA (Lorentz transformations based on absolute simultaneity) reflecting a preferred frame theory [6].

As seen from frame S in Fig. 1, light propagation is the same for standard SR (based on the LT) and for the preferred frame theory based on the LTA [6]. Then, clocks on S may be synchronized using the one-way light speed c, and we may calculate the time interval measured from frame S when a light signal is sent at $t = t' = 0$ from A to B. Traveling at speed c, light reaches point B moving at speed v, when $ct = L/\gamma + vt$ and,

$$t_B = \frac{L}{\gamma(c - v)}, \tag{1}$$

where L/γ represents the Lorentz contracted length of the moving rod.

a) LT. According to standard SR based on the LT (8), the synchronization performed by means of the rotating rod is assumed to be equivalent to Einstein synchronization and, at the local speed c, the photon from A reaches B after the interval,

$$t'_B = \frac{L}{c}, \tag{2}$$

as measured by clock B from frame S′. The result (2) is in agreement with the time transform of the LT, $t' = \gamma(t - vx/c^2) = L/c$, by setting $t = t_B$ and $x = ct_B$ in the time transform. If the experiment is performed, the LTs foresee that the reading of clock B is given by (2) if either Einstein or the equivalent natural sync is adopted in S′.

b) LTA. According to the LTA (8), which are the transformations conserving simultaneity,

$$t'_B = \frac{t_B}{\gamma} = \frac{L}{\gamma^2(c - v)} = \frac{L}{c'}. \tag{3}$$

Hence, the LTAs foresee an observable result different from that of the LT, indicating that the physical reality they describe is not the same. Since, in principle, there are no reasons to assume that the natural sync is equivalent to Einstein's, the view of Mansouri and Sexl and conventionalists can be tested by adopting in S′ the natural sync and then measuring the one-way light speed of the photon traveling from A to B. If the result is $c' = \gamma^2(c - v) \neq c$ as in (3), conventionalism and light speed invariance will be disproved. Of course, if the internal sync adopted in S′ is equivalent to Einstein's, the observed result will be $t'_B = L/c$ as in (2) in agreement with the conventionalist view and light speed invariance.

Let us change the orientation of the rotating rod and place it along the y' axis, with the light ray now sent from A to B in the y' direction. As seen from frame S, traveling at speed c, light reaches B when, with $c_x = v$, $c_y t = L$ and, with $c_y = (c^2 - v^2)^{1/2} = c/\gamma$,

$$t_B = \frac{\gamma L}{c}. \tag{4}$$

According to the LT, with $x = x_B = vt$, $t' = \gamma(t - vx/c^2) = \gamma t_B(1 - v^2/c^2) = \gamma^2 L(1 - v^2/c^2)/c = L/c$ and,

$$t'_B = t' = \frac{L}{c}. \tag{5}$$

The results (2) and (5) indicate that, for the LT, light speed is isotropic in frame S′.

According to the LTA,

$$t'_B = \frac{t_B}{\gamma} = \frac{L}{c}. \tag{6}$$

Hence, in view of results (3) and (6), we may conclude that for the LTA the light speed depends on v and the orientation and, by repeating the experiment in different directions, the natural sync can be used to detect the velocity $\mathbf{v}$ of S′ relative to the preferred frame S.

An important consequence of our natural sync is that, a priori, the one-way light speed is not conventional and standard SR based on the LT is a viable falsifiable theory that can be tested, as required by epistemologists [4], [5].

4. Conclusion

We have described a kinematical system composed of a long rod AB in uniform rotational motion with a natural built-in simultaneity connecting the spatially separated points A^* and B^*. In principle, the inherent simultaneity of the system can be exploited to "internally" synchronize the two clocks at A and B, and then measure the one-way speed of light and test Lorentz invariance. Although the transmission of information with Einstein synchronization (and, e.g., clock transport) is bound to occur at speeds no faster than c, the rod preset simultaneity reflects an instantaneous synchrony. If the experiment is realized, the synchronization by means of the built-in simultaneity is equivalent to Einstein's only if, as predicted by standard SR, the results (2) and (5) confirm light speed invariance.

Besides other approaches for measuring the one-way light speed [8]–[10], the approach presented here highlights just one of the various other physical situations (mentioned in Refs. [16]–[27], [30]–[37]) where, at least in principle, a relativistic theory based on relative simultaneity (LT) foresees observable results different from those predicted by a theory based on absolute simultaneity (LTA). Hence, in general, synchronization is not arbitrary and different transformations (8) are not physically equivalent.

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Data Availability Statement

No new data were created or analyzed in this study.

Appendix

A relativistic theory can be described either with the standard LT, based on relative simultaneity, or other transformations with different synchronization, e.g., the LTA [19]–[23], used with different names by several physicists (Tangherlini transforms [24], Selleri transforms [16]–[18], [25], ALT [26], [27], etc.).

According to physicists [6], [28], [29] adhering to the "conventionalist" view, the LT and LTA are physically equivalent and interchangeable and represent the same physical reality, even if they adopt different, conventional values for the one-way light speed. Following Mansouri and Sexl, for the transformations from S to S′ in terms of the synchronization parameter ε, we have [6], [19]–[23],

$$\begin{aligned} t' &= t/\gamma - \varepsilon x'/c^2 \\ x' &= \gamma(x - vt) \quad y' = y \quad z' = z \\ c' &= c'(\varepsilon) = \frac{dx'}{dt'} = \frac{c}{1 + v/c - \varepsilon/c}. \end{aligned} \tag{7}$$

$$\varepsilon = v \qquad \text{LT}$$

$$t' = \gamma(t - vx/c^2) \qquad c' = c$$

$$\varepsilon = 0 \qquad \text{LTA}$$

$$t' = t/\gamma \qquad c' = \frac{c}{1 + v/c} = \gamma^2(c - v) \tag{8}$$

Conflict of Interest

The author declares no conflict of interest.

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