Another Test of the Light Speed Invariance Postulate

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Abstract

In a paper in 1910 Tolman pointed out that the light speed invariance postulate of special relativity requires that the time for light to traverse a fixed distance between two points is independent of the movement of those points relative to the light source. The range equation of the GPS is used to directly test this proposition. This equation has been rigorously tested and verified in the Earth-Centred Inertial frame where light signals propagate in straight lines at constant speed *c*. The result is a simple demonstration of light speed variation that is consistent with light speed variation detected in other experiments and inconsistent with the light speed invariance postulate.

Keywords: Special theory of relativity, Light speed invariance postulate, GPS, Range equation, ECI frame

1. Introduction

The light speed invariance postulate holds that the speed of light is constant in all inertial frames (French, 1965; Zhang, 1997; Williams, 2002; Rindler, 2006). This second postulate of special relativity is counterintuitive and not surprisingly therefore many objections have been raised over the 100 year history of the theory. In this regard a particularly interesting comment about this postulate was made by Tolman in 1910 shortly after the publication of the theory (Tolman, 1910). Referring to a similar Figure 1 he said the following:

"A simple example will make the extraordinary nature of the second postulate evident. *S* is a source of light and *A* and *B* two moving systems. *A* is moving towards the source *S,* and *B* away from it. Observers on the systems mark off equal distances *aa'* and *bb'* along the path of the light and determine the time taken for light to pass from *a* to *a'* and *b* to *b'* respectively. Contrary to what seem the simple conclusions of common sense, the second postulate requires that the time taken for the light to pass from *a* to *a'* shall measure the same as the time for the light to go from *b* to *b'*."

The advent of the GPS now makes it possible to test this prediction of the second postulate of special relativity.

The GPS is a modern navigational system with accurate synchronized atomic clocks that enable precise navigation on the Earth (Ashby, 2003). It has been hailed as a working example of the application of special relativity (Ashby, 1994; Ashby, 2003; Will, 2006). According to the IS-ICD-200 GPS Interface Specification, GPS signals propagate in straight lines at the constant speed *c* in an Earth-Centered Inertial (ECI) frame, a frame that moves with the Earth but does not share its rotation. This light speed constancy in the ECI frame is applied in the GPS range equation given by (Ashby, 1994; Ashby, 2003)

$$\left|\overline{r_r}(t_r)-\overline{r_s}(t_s)\right|=c(t_r-t_s) \tag{1}$$

where t_s is the time of transmission of an electromagnetic signal from a source, t_r is the time of reception of the electromagnetic signal by a receiver both times determined using synchronized clocks, $r_s(t_s)$ is the position of the source at the time of transmission of the signal and $r_r(t_r)$ is the position of the receiver at the time of reception of the signal. Using elapsed time measurements determined by the synchronized clocks and the light speed value *c*, equation (1) allows accurate determination of the instantaneous position of objects which are stationary or moving on the surface of the Earth. It has been exhaustively and rigorously tested and verified and the system's very successful operation has resulted in the world-wide proliferation of GPS technology.

In this paper we employ features of the GPS operating in the ECI frame to test the prediction of the light speed invariance postulate outlined by Tolman.

2. Tolman's Test in the ECI Frame

In Figure 1 consider a light source S fixed in the ECI frame and two systems A and B moving uniformly in the ECI. A is moving towards the source at a constant speed *v* relative to the ECI frame and B is moving away from the source at a constant speed *v* relative to the ECI frame. Observers on the two systems mark off equal distances *aa′* and *bb′* equal to *D* along the light path and determine the time taken for the light to pass from *a* to *a′* and *b* to *b′* respectively. As Tolman has observed, "the second postulate [of special relativity] requires that the time taken for the light to pass from *a* to *a′* shall measure the same as the time for the light to go from *b* to *b′*." According to the second postulate this measured time must be D/c on both systems. This prediction will now be tested using the range equation of the GPS.

2.1 Analysis on System A

Let GPS stations be placed at a and a' respectively. On an axis fixed in the ECI frame along the line *aa′* joining the two stations with station *a* closer to the origin O than station *a′* and taking positive values, let $x_a(t)$ be the position of station *a* at time *t* and $x_{a'}(t)$ be the position of station *a′* at time *t*. Let light from S arrive at station *a* at time t_I and later at station *a′* at time t_F. Then using the range equation (1) and noting that $x_{a'}(t_F) > x_a(t_I)$,

$$x_{a'}(t_F) - x_a(t_I) = c(t_F - t_I) \tag{2}$$

Since both stations are moving uniformly toward S at speed *v* relative to the ECI frame, it follows that the relation between the position $x_{a'}(t_F)$ of station *a′* at the time of its reception of the signal and its earlier position $x_{a'}(t_I)$ is given by

$$x_{a'}(t_F) = x_{a'}(t_I) - v(t_F - t_I) \tag{3}$$

Substituting $x_{a'}(t_F)$ from (3) in (2) yields

$$x_{a'}(t_I) - x_a(t_I) - v(t_F - t_I) = c(t_F - t_I) \tag{4}$$

Since $x_{a'}(t_I) - x_a(t_I) = D$ then (4) becomes

$$x_{a'}(t_I) - x_a(t_I) = D = (c+v)(t_F - t_I) \tag{5}$$

Hence for an observer on system A the range equation gives the time for light to travel between a and a' as

$$t_F - t_I = \frac{D}{c+v} \tag{6}$$

Thus the light travel time measured by an observer on A is $D/(c+v)$ and not D/c as required by the light speed invariance postulate. Therefore the light speed $c_{aa'}$ detected on system A for the light traveling from station *a* to station *a′* is given by the fixed length D divided by elapsed time $(t_F - t_I)$ which using (6) is given by

$$c_{aa'} = \frac{D}{(t_F - t_I)} = \frac{D}{D/(c+v)} = c+v \tag{7}$$

2.2 Analysis on System B

Let GPS stations be placed at *b* and *b′* respectively. On an axis fixed in the ECI frame along the line bb′ joining the two stations with station b closer to the origin O than station b′ and taking positive values, let $x_b(t)$ be the position of station b at time *t* and $x_{b'}(t)$ be the position of station b′ at time *t*. Let light from S arrive at station b at time t_I and later at station b′ at time t_F. Then using the range equation (1),

$$x_{b'}(t_F) - x_b(t_I) = c(t_F - t_I) \tag{8}$$

Since both stations are moving uniformly away from S at speed *v* relative to the ECI frame, it follows that the relation between the position $x_{b'}(t_F)$ of station b′ at the time of its reception of the signal and its earlier position $x_{b'}(t_I)$ is given by

$$x_{b'}(t_F) = x_{b'}(t_I) + v(t_F - t_I) \tag{9}$$

Substituting $x_{b'}(t_F)$ from (9) in (8) yields

$$x_{b'}(t_I) - x_b(t_I) + v(t_F - t_I) = c(t_F - t_I) \tag{10}$$

Since $x_{b'}(t_I) - x_b(t_I) = D$ then (10) becomes

$$x_{b'}(t_I) - x_b(t_I) = D = (c - v)(t_F - t_I) \tag{11}$$

Hence for an observer on system B the range equation gives the time for light to travel between *b* and *b'* as

$$t_F - t_I = \frac{D}{c - v} \tag{12}$$

Thus the light travel time measured by an observer on B is $D/(c-v)$ and not D/c as required by the light speed invariance postulate. Therefore the light speed $c_{bb'}$ observed on system B for the light traveling from station *b* to station *b'* is given by the fixed length D divided by elapsed time $(t_F - t_I)$ which using (12) is given by

$$c_{bb'} = \frac{D}{(t_F - t_I)} = \frac{D}{D/(c-v)} = c - v \tag{13}$$

2.3 Discussion

As is evident from equations (6) and (12) the light travel times $D/(c+v)$ and $D/(c-v)$ over the distance D on systems A and B are not the value D/c predicted by the second postulate of special relativity. This is because the light speeds $c+v$ and $c-v$ observed on systems A and B in equations (7) and (13) are different from the value c required by the second postulate. Light speed variation as demonstrated here has also been observed using the synchronized clocks of the GPS (Marmet, 2000; Kelly, 2005; Gift, 2010a), in the Roemer experiment for light from the occultations of planetary moons (Gift, 2010b), in the Doppler experiment for light from stars on the ecliptic (Gift, 2010c) and in the Shtyrkov experiment involving light aberration with respect to geostationary satellites (Shtyrkov, 2005).

The light speeds $c \pm v$ for moving observers determined using the range equation in the ECI frame were not detected in numerous light speed experiments (Zhang, 1997) which all gave light speed *c*. These changed light speed values $c \pm v$ observed in an inertial frame directly contradict the light speed invariance postulate which requires constant light speed *c* that is independent of the motion of the observer. This is vindication of the criticisms of special relativity expressed by Tolman and other researchers over the period of the 20th century up to today.

Interestingly, in an attempt to avoid what he referred to as the "complications introduced by the theory of relativity" arising from "the extraordinary nature of the second postulate" Tolman considered the idea that "The velocity of light and other electromagnetic propagations might not be independent of the motion of the source, but their velocity and that of the source might be additive." He continued, "This assumption would be very simple, would be no contradiction to the first postulate of relativity, and would directly explain all our failures to detect an ether drift." However apart from the evidence showing otherwise (Zhang, 1997), the range equation easily shows that this assumption is not true: Consider a GPS station A moving at a constant speed *v* relative to the ECI frame and a GPS station B fixed in the ECI frame. On an axis fixed in the ECI frame along the line joining the two stations with station A closer to the origin O than station B and taking positive values, let $x_A(t)$ be the position of station A at time *t* and x_B be the fixed position of station B. At time t_I let the distance between the two stations be D given by

$$x_B - x_A(t_I) = D \tag{14}$$

Consider the case of station A moving directly toward fixed station B. At time t_I let station A transmit a signal directly to station B which receives it at time t_F. Then using the range measurement equation (1)

$$x_B - x_A(t_I) = c(t_F - t_I) \tag{15}$$

where $x_A(t_I)$ is the position of station A at time t_I. Using (14) in (15) gives

$$x_B - x_A(t_I) = D = c(t_F - t_I) \tag{16}$$

Hence for an observer on station B the range measurement equation yields the elapsed time as

$$t_F - t_I = \frac{L}{c} \tag{17}$$

Therefore the speed c_{AB} of the light relative to station B for the light traveling from the moving station A to the fixed station B is given by initial separation D divided by elapsed time $(t_F - t_I)$ which using (17) is

$$c_{AB} = \frac{D}{(t_F - t_I)} = \frac{D}{D/c} = c \tag{18}$$

On the basis of (18) we conclude that light speed is independent of the movement of the source toward the observer. This follows from the fact that only the initial source position is involved in (15) and hence the movement of the source does not affect the elapsed time determination in (17). As a result movement of the source in any direction relative to station B will yield the same result (18) and therefore the speed of light is independent of the motion of the source.

It turns out that the alternative theory sought by Tolman is now available: It is the Absolute Space Theory of the Selleri (Inertial) Transformations (Selleri, 2004). This theory was shown (Gift, 2009) to be the best description of space and time, and that special relativity based on the Lorentz transformations along with all theories that are derived from members of the complete set of "equivalent" space-time transformations are invalid representations of the physical world.

3. Conclusion

In this paper, elementary analysis involving the fully tested and verified range equation of the GPS was used to test a requirement of the light speed invariance postulate in a form stated by Tolman. The basis of this is that the GPS range equation yields distances in frames that are stationary or moving relative to the ECI and the GPS synchronized clocks enable the determination of time in those frames. Thus while in GPS navigation these measured times are used in the range equation to determine position, in this paper known positions x_a, $x_{a'}$, x_b and $x_{b'}$ are used in the range equation to determine elapsed time $t_F - t_I$ in (6) and (12). Because the range equation has been rigorously and exhaustively tested and verified, these elapsed times (6) and (12) are exactly the times that would be measured in a physical test using the GPS clocks. The speed calculations that follow in equations (7) and (13) are therefore completely legitimate.

The detected light speed variation $c \pm v$ is a direct demonstration of light speed variation in the ECI frame arising from the movement of the observers in systems A and B and is consistent with variation results previously obtained (Marmet, 2000; Kelley, 2005; Shtyrkov, 2005; Gift, 2010a; Gift, 2010b; Gift, 2010c). It contradicts the light speed invariance postulate of special relativity which is formulated in inertial frames though is today routinely applied in the non-inertial frame of the surface of the Earth.

From this and previous work it is evident that light speed variation is a phenomenon that is easily detected by GPS and other technology. It undermines the Lorentz invariant requirement of the relativistic worldview and may perhaps hold the key to the resolution of the problem of the lack of progress in fundamental physics experienced over the past 25 years (Smolin, 2006).

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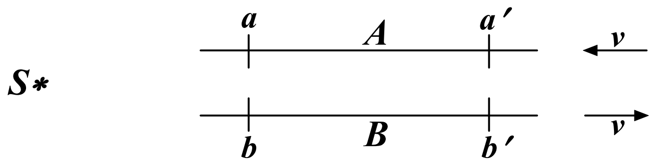

Figure1. Test of Light Speed Invariance