

Sidereal Time Distribution in Large-Scale of Orbits by using Astronomical Algorithm Method

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Abstract: Sidereal Time literally means star time. The time we are used to using in our everyday lives is Solar Time. Astronomy, time based upon the rotation of the earth with respect to the distant stars, the sidereal day being the unit of measurement. Traditionally, the sidereal day is described as the time it takes for the Earth to complete one rotation relative to the stars, and help astronomers to keep their telescopes directions on a given star in a night sky. In other words, earth's rate of rotation determine according to fixed stars which is controlling the time scale of sidereal time. Many reserachers are concerned about how long the earth takes to spin based on fixed stars since the earth does not actually spin around 360 degrees in one solar day. Furthermore, the computations of the sidereal time needs to take a long time to calculate the number of the Julian centuries. This paper shows a new method of calculating the Sidereal Time, which is very important to determine the stars location at any given time. In addition, this method provdes high accuracy results with short time of calculation.

Keywords: Sidereal time; Orbit allocation; Geostationary Orbit; Solar Days; Sidereal Day

1. Introduction

The word "sidereal" comes from the Latin word sider, meaning star. A sidereal day is defined as the time required for the earth to travel 360° around its axis[1]. A geostationary satellite therefore must have an orbital period of one sidereal day in order to appear stationary to an observer on earth. The sidereal day is the time it takes for the Earth to complete one rotation about its axis with respect to the 'fixed' stars. By fixed, we mean that we treat the stars as if they were attached to an imaginary celestial sphere at a very large distance from the Earth[2]. A measurement of the sidereal day is made by noting the time at which a particular star passes the celestial meridian (i.e. directly overhead) on two successive nights. On Earth, a sidereal day lasts for 23 hours 56 minutes 4.091 seconds, which is slightly shorter than the solar day measured from noon to noon[1]. Our usual definition of an Earth day is 24 hours, so the sidereal day is 4 minutes faster. This means that a particular star will rise 4 minutes earlier every night, and is the reason why different constellations are only visible at specific times of the year[1].

In daily life we are used to time measured with reference to the sun. A solar day is defined as time between the successive passages of the sun over a local meridian[3]. On closer examination it becomes apparent that the earth revolves by more than 360° for successive passage of the sun over a point because the earth itself travels, on average, a further 0.986° per day around the sun[4]. A sidereal month is the average period of revolution of the Moon around the Earth with respect to a fixed star, equal to 27 days, 7 hours, 43 minutes of solar time[5]. A sidereal year is the time required for one complete revolution of the Earth around the Sun with respect to a fixed star, equal to 365 days, 6 hours, 9 minutes, 9.54 seconds of solar time[5].

2. Background

Solar time is based on the position of the sun. Local noon in solar time is the moment when the sun is at its highest point

(the upper meridian) in the sky[6]. Solar time is what the time we all use where a day is defined as 24 hours, which is the average time that it takes for the sun to return to its highest point, see figure 1.

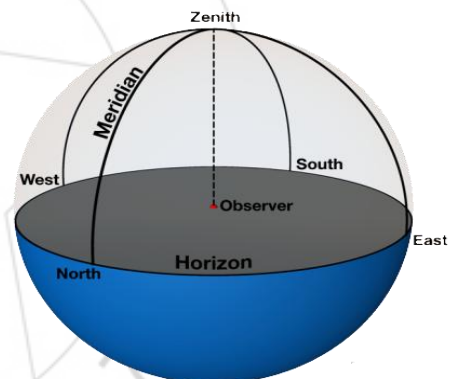


Figure 1: Earth observer

To an astronomer, the sky is like a map, divided into 24 hours. Sidereal time helps these scientists determine where a given star or set of stars is, at any given time[1]. The difference between solar and sidereal time is not much over an hour or a day, but adds up to a very large difference over a period of months and years[7]. This can be observed even without a telescope. If a person were to look at or photograph the night sky at the same time every night, he would notice that the stars as a whole shift to the west over time. The formula relating the lengths of the sidereal and solar days is number of sidereal days per orbital period = 1 + number of solar days per orbital period or equivalently

$$\text{Length of solar day} = \frac{\text{length of sidreal day}}{1 - \frac{\text{lengt h of sidereal day}}{\text{orbital period}}} \quad (1)$$

On the other hand, the formula in the case of retrograde rotation (Retrograde motion is motion in the direction opposite to the movement of something else, and is the contrary of direct or prograde motion) is:

Number of sidereal days per orbital period = - 1 + number of solar days per orbital period or equivalently

$$\text{Length of solar day} = \frac{\text{length of sidereal day}}{1 + \frac{\text{length of sidereal day}}{\text{orbital period}}} \quad (2)$$

All the solar planets more distant from the sun than Earth are similar to Earth in that, since they experience many rotations per revolution around the sun, there is only a small difference between the length of the sidereal day and that of the solar day the ratio of the former to the latter never being less than Earth's ratio of 997. But the situation is quite different for Mercury and Venus. Mercury's sidereal day is about two-thirds of its orbital period, so by the prograde formula its solar day lasts for two revolutions around the sun three times as long as its sidereal day. Venus rotates retrograde with a sidereal day lasting about 243.0 earth-days, or about 1.08 times its orbital period of 224.7 earth-days; hence by the retrograde formula its solar day is about 116.8 earth-days, and it has about 1.9 solar days per orbital period[5], as shown in figure 2.

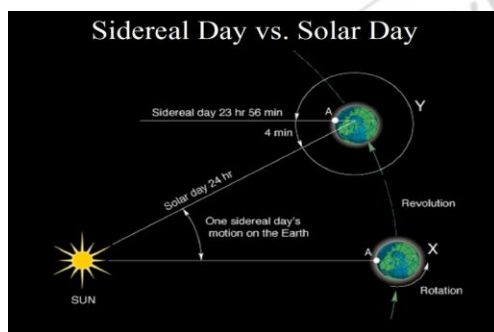


Figure 2: Sidereal day vs. Solar day

3. Sidereal Time

Sidereal Time means time of star. Solar Time is the time using in our everyday lives. The fundamental unit of Solar Time is a Day: the time it takes the Sun to travel 360 degrees around the sky, due to the rotation of the Earth[1]. Smaller units of Solar Time are just divisions of a Day:

- 1/24 Day = 1 Hour
- 1/60 Hour = 1 Minute
- 1/60 Minute = 1 Second

However, there is a problem with Solar Time. The spinning of the Earth does not actually around 360 degrees in one Solar Day. The Earth is in orbit around the Sun, and over the course of one day, it moves about one Degree along its orbit (360 degrees/365.25 Days for a full orbit = about one Degree perDay). So, in 24 hours, the direction toward the Sun changes by about a Degree. Therefore, the Earth has to spin 361 degrees to make the Sun look like it has traveled 360 degrees around the Sky[3].

In astronomy, we are concerned with how long it takes the Earth to spin with respect to the “fixed” stars, not the Sun. So, we would like a timescale that removes the complication of Earth's orbit around the Sun, and just focuses on how long it takes the Earth to spin 360 degrees with respect to the stars. This rotational period is called a Sidereal Day. On average, it is 4 minutes shorter than a Solar Day, because of the extra 1 degree the Earth spins in a Solar Day. Rather than defining a Sidereal Day to be 23 hours, 56 minutes, we define Sidereal Hours, Minutes and Seconds that are the same fraction of a Day as their Solar counterparts. Therefore, one Solar Second = 1.00278 Sidereal Seconds[7].

The Sidereal Time is useful for determining where the stars are at any given time. Sidereal Time divides one full spin of the Earth into 24 Sidereal Hours; similarly, the map of the sky is divided into 24 Hours of Right Ascension. This is no coincidence; Local Sidereal Time (LST) indicates the Right Ascension on the sky that is currently crossing the Local Meridian. So, if a star has a Right Ascension of 05h 32m 24s, it will be on your meridian at LST=05:32:24. More generally, the difference between an object's RA and the Local Sidereal Time tells you how far from the Meridian the object is. For example, the same object at LST=06:32:24 (one Sidereal Hour later), will be one Hour of Right Ascension west of your meridian, which is 15 degrees. This angular distance from the meridian is called the object's Hour Angle[5].

A. Difference between a Solar and Sidereal Day

The difference between a solar and sidereal day illustrated in figure 3. The blue circle is the Earth, the small yellow circle is the Sun. The star is not actually shown, since it's very far away. Because of this great distance, the rays of light coming from this star can be considered to be parallel, that is, there is no parallax over the course of two observations, taken 1 day apart. The rays of light from the star are shown, in orange. A sidereal day would be the time between two successive occasions when the star is directly above the local meridian. This period is approximately 23 hours and 56 minutes. If the Sun was as far as the star, the solar day would also be exactly the same length. However, the Sun is much nearer, and during the course of a day, the Earth has moved in its orbit by about 1/365 of a circle, or 1 degree. Therefore, at the end of the sidereal day, the Sun is still not directly over the local meridian; it is in fact, about 1 degree behind. The Earth's rotation will bring the Sun directly over the local meridian about 4 minutes later, which is the end of one solar day. The solar day is 24 hours, about 4 minutes longer than the sidereal day.

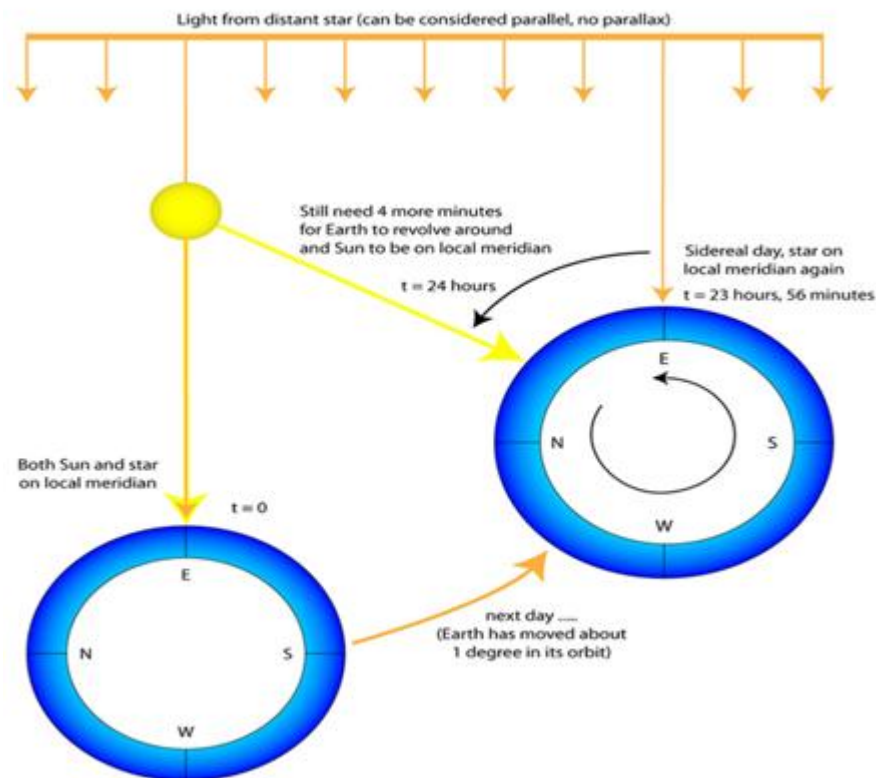


Figure 3: Difference between Sidereal Day and Solar Day

The relationship between a solar and sidereal day is easy to see intuitively. A year is 365 days long, meaning there are 365 solar days in it. In other words, 365 times during the year, the Sun is directly over the local meridian. But how many times has the earth rotated with respect to the stars? The answer is 365+1, with the extra 1 coming from the fact that during a full circle in orbit, the earth has rotated 365 times plus the one time any non-rotating or tidally locked body would rotate with respect to the stars during a full orbit. In actual fact, the length of a solar year is 365.25 days, so the relationship between a sidereal and solar day is 365.25/366.25, or 23 hours, 56 minutes, 4.1 seconds[7].

4. Specification of Geostationary Orbit

A geostationary orbit has specific orbital parameters. It is first of all a circular orbit. This means that it has an eccentricity of zero - its distance from the center of the Earth is always the same (42,165 km). Furthermore, it has an orbital inclination of zero - its orbital plane is identical to the Earth's equatorial plane. Lastly, it has a period (related to its orbital radius) of 86164 seconds (about 23 hours 56 minutes 4 seconds), which is the time it takes the Earth to rotate through 360 degrees. The location of a satellite is usually computed using an ephemeris program and a set of orbital elements. However, for a stationary Geosat, this is unnecessary and its position may be computed using only geometry. The only parameter needed to specify a Geosat is its longitude. This is the same as the longitude of a point on the Earth's equator directly below the satellite itself[8, 9].

Geosat longitude may be specified from 0 to 360 degrees, measured eastward around the equator from the zero degree meridian passing through Greenwich, England. Alternatively

it might be specified from 0 to +180 degrees (east) and 0 to -180 degrees (west). Note that +180 and -180 are the same point[9].

5. Orbit Allocation

In satellite communication network, low earth orbit (LEO) satellite has become more popular than geostationary earth orbit satellite (GEO) due to their low propagation delay and low power requirements. During the course of movement of the LEO satellite, the area covered by its spot-beam (the footprint region of a satellite is divided into a number of clusters of cells which is known as spot-beam) is changing very rapidly. Thus the handover of connections from one spot-beam to other spot-beam is required. But their high relative speed and random direction of motion provide a serious barrier for such services to be made available to wireless communication[10].

Satellites in geostationary orbit must all occupy a single ring above the Equator. The requirement to space these satellites apart to avoid harmful radio-frequency interference during operations means that there are a limited number of orbital "slots" available, thus only a limited number of satellites can be operated in geostationary orbit. This has led to conflict between different countries wishing access to the same orbital slots (countries near the same longitude but differing latitudes) and radio frequencies. These disputes are addressed through the International Telecommunication Union's allocation mechanism.

6. Determination of Sidereal Time

The computations of the sidereal time needs to take a long time to calculate the number of the Julian centuries, then calculating the sidereal time by applying the formula:

$$ST = UT(sec) \times 1.0027379 + 24110.54841 + 8640184.812866 \times T + 0.093104 \times T^2 - 6.2 \times 10^{-6} \times T^3 \quad (3)$$

A PC- based program is designed to calculate the sidereal time simply by entering the parameter. This program is designed using the VisualStudio6.0 codes. The figure 4 shows the welcome screen of the program.

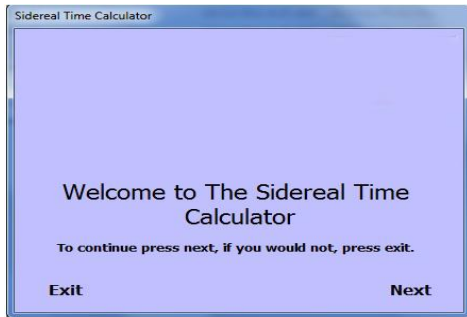


Figure 4: Welcome Screen

The welcome screen contains two buttons (Exit, Next) by pressing the (Exit) button the program will be closed. But, by pressing the (Next) button a second window will appear as shown in figure 5.

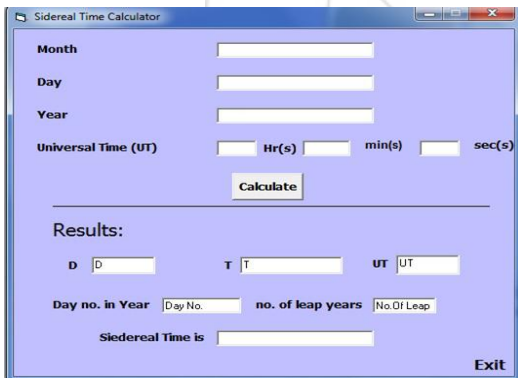


Figure 5: Second Screen of The Program

The second screen contains all the required variables that must be entered to calculate the sidereal time. As it shown, the user must enter the date that he wants including the (month, day, year), the universal time (UT). After that only by pressing the calculate button all the results will be shown in the results field.

7. Results and Discussions

A. First Experiment

In this section after designing the program by VisualStudio6.0 codes and inserted the formula that use to calculate the sidereal time in the program, different parameters are used to ensure the validity of the results are correct, and to find the accurate results of sidereal time in short period. In this part, we considered the date is 1 jan 2008, so in the program will put in Month box: jan, Day

box: 1, and in Year box: 2008. After ran the program the results are: D= 2921.5, T= 7.998631074606438, UT= 0, Day No. in year= 1, No. of leap years= 2, and is Sidereal Time= 715207.056350984, as shown in figure 6.

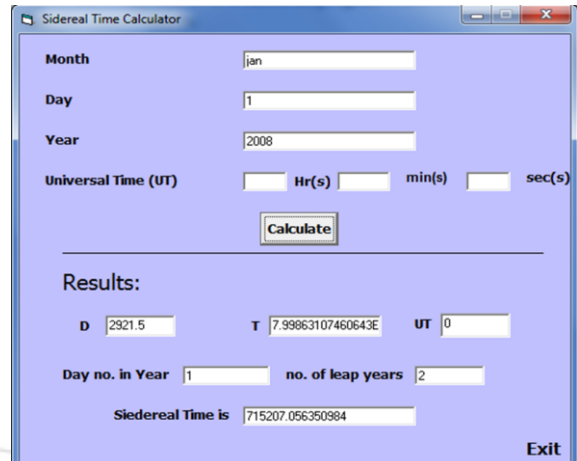


Figure 6: Calculating of Sidereal Time with year 2008

B. Second Experiment

In this part, used the same scenario of first experiment, but with different parameters, to ensure the reliability of the formula in the program. In the Month box put jun, Day box put 20, and Year box put 2014. The results of these information are: D= 5283.5, T= 0.144654346338125, UT= 0, Day No. in year= 171, No. of leap years= 4, and Sidereal Time= 1273950.83670389, as shown in figure 7.

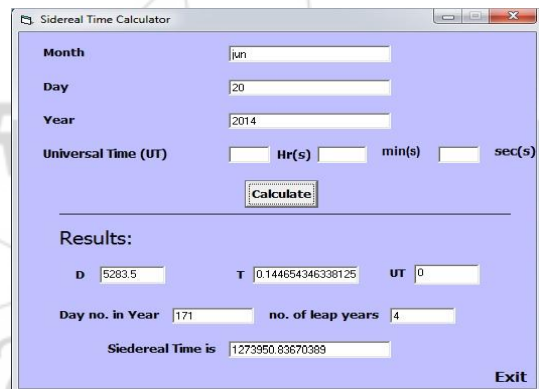


Figure 7: Calculating of Sidereal Time with year 2014

8. Conclusion

Sidereal time is a time-keeping system, astronomers use to keep track of the direction to point their telescopes to view a given star in the night sky. Briefly, sidereal time is a "time scale that is based on the Earth's rate of rotation measured relative to the fixed stars. The most challenging is the earth does not actually spin around 360 degrees in one Solar Day, and astronomers are concerned with how long it takes the Earth to spin with respect to the "fixed" stars, not the Sun. Thus, the Sidereal Time is necessary for determining where the stars are at any given time. Furthermore, the computations of the sidereal time needs to take a long time to calculate the number of the Julian centuries. Consequently, high speed and high performance is required to ensure optimum calculations. This research, come out with method to calculate the sidereal time in short period and high

accuracy results by implementing the formula of ST in Visual Studio codes. In conclusion, all the objectives of this research had been successfully achieved. In terms of high accuracy and short time of calculation.

References

- [1] Barbour, J., *The nature of time*. arXiv preprint arXiv:0903.3489, 2009.ed., vol. 2. Oxford: Clarendon, 1892, pp.68-73.
- [2] Spottiswoode, S.J.P., Apparent association between effect size in free response anomalous cognition experiments and local sidereal time. *Journal of Scientific Exploration*, 1997. **11**(2): p. 109-122.
- [3] Drever, R.W., A search for anisotropy of inertial mass using a free precession technique. *Philosophical Magazine*, 1961. **6**(65): p. 683-687.
- [4] Capitaine, N. and A.-M. Gontier, Accurate procedure for deriving UT1 at a submilliarcsecond accuracy from Greenwich Sidereal Time or from the stellar angle. *Astronomy and Astrophysics*, 1993. **275**: p. 645.
- [5] Smylie, D., G. Clarke, and T. Ulrych, *Analysis of irregularities in the earth's rotation*. *Methods in computational physics*, 2012. **13**: p. 391-430.
- [6] Guinot, B., *Solar time, legal time, time in use*. *Metrologia*, 2011. **48**(4): p. S181.
- [7] Zaatri, A., et al., Comparison of the sidereal angular velocity of subphotospheric layers and small bright coronal structures during the declining phase of solar cycle 23. arXiv preprint arXiv:0907.4099, 2009.
- [8] Kang, G., et al., *An in-orbit radiometric calibration method of the geostationary ocean color imager*. *Geoscience and Remote Sensing, IEEE Transactions on*, 2010. **48**(12): p. 4322-4328.
- [9] Goodman, S.J., et al., *The GOES-R Geostationary Lightning Mapper (GLM)*. *Atmospheric Research*, 2013. **125**: p. 34-49.
- [10] Sarddar, D., et al., An Adaptive Scheme for Efficient Utilization of Resources in Handover and New Channel Allocation in LEO Satellites. *Programmable Device Circuits and Systems*, 2011. **3**(14): p. 808-815.