Calculation of the solar time for a given location from the time zone and GPS coordinates

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Tamás Stonawski, Imre Beszeda, Ádám Poór
University of Nyíregyháza, Nyíregyháza, 4400 Sóstói street 31, Hungary

E-mail: stonawski@gmail.com

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Abstract

Initially, people calculated the current time based on the position of the Sun. True local noon was when the center of the solar disk passed over the meridian at the observation site, i.e., when the shadow of a vertically placed stick pointed north. Naturally, this implies that at any given moment, each geographical location has a different true local time unless they lie on the same meridian. Previously, each city had its own time. Therefore, travelers had to adjust their watches in every city to align with local customs and not miss scheduled appointments. To solve these problems, zone time was introduced. In this article, I describe a method by which local solar time can be calculated from zone time, and readers can download the application I developed for free on their phones.

Keywords: Astronomy, Solar time, GPS.

Resumen

En un principio, la gente calculaba la hora actual basándose en la posición del Sol. El mediodía local verdadero se producía cuando el centro del disco solar pasaba por encima del meridiano del lugar de observación, es decir, cuando la sombra de un palo colocado verticalmente apuntaba hacia el norte. Naturalmente, esto implica que, en un momento dado, cada ubicación geográfica tiene una hora local verdadera diferente, a menos que se encuentren en el mismo meridiano. Antes, cada ciudad tenía su propia hora. Por lo tanto, los viajeros tenían que ajustar sus relojes en cada ciudad para que se adaptaran a las costumbres locales y no perdieran las citas programadas. Para resolver estos problemas, se introdujo la hora de zona horaria. En este artículo, describo un método mediante el cual se puede calcular la hora solar local a partir de la hora de zona horaria, y los lectores pueden descargar la aplicación que desarrollé de forma gratuita en sus teléfonos.

Palabras clave: Astronomía, Hora solar, GPS.

I. INTRODUCTION

"Time is what the clocks show."

ChatGPT 3.5

In the past, the current time was calculated based on the movement of the Sun on the sky, later mechanical clocks also were set to this time. It was noon when the center of the sun-disc passed through the meridian at the observation site, that is, when the shadow of a pole stuck vertically into the horizontal ground was pointing north. The consequence of this method was that geographical locations not on the same meridian had different real local times at a given moment. That is, before the modern era, almost each city had its own time.

Travelers and merchants therefore had to conform to the local time in each city, so that not to be late for an appointment, for instance.

To remedy such problems, time zones were introduced in cities close to each other, and in 1876, a proposal was made to extend time zones to cover the entire Earth. Time zones are in use even today. The advantage of this is that the officially accepted time is the same throughout the entire territory of small countries.

Western European time applies in the 15-degree band around the prime meridian that includes Greenwich. In the neighboring zone from the east, the Central European time applies, where the time difference compared to Greenwich is exactly 1 hour. The next zone is the Eastern European time zone, where it is two hours later compared to Greenwich, and so on, and in 24 hours we got around the Earth, since $15°\cdot 24=360°$.

II. LOCAL TIME FROM THE TIME ZONE

Since people entrust time measurement to their mobile phones nowadays, it is obvious that the local time should somehow be calculated from it, and it can also be displayed with the help of an app. For the first round, calculations do not require advanced mathematics, i.e. it can be easily understood even by high school students.

If it is just noon on the red curve in Figure 1, the question may arise how many minutes later will be 12 noon (the Sun is at its apparent highest point in the sky) on the green curve, 1° west of it (green curve). The answer is obtained from the following direct proportionality:

$$360° \rightarrow 24\ hours = 24 \cdot 60\ minutes, \text{ thus:}$$

$$1° \rightarrow \frac{24 \cdot 60\ minutes}{360°} = 4\ minutes. \qquad (1)$$

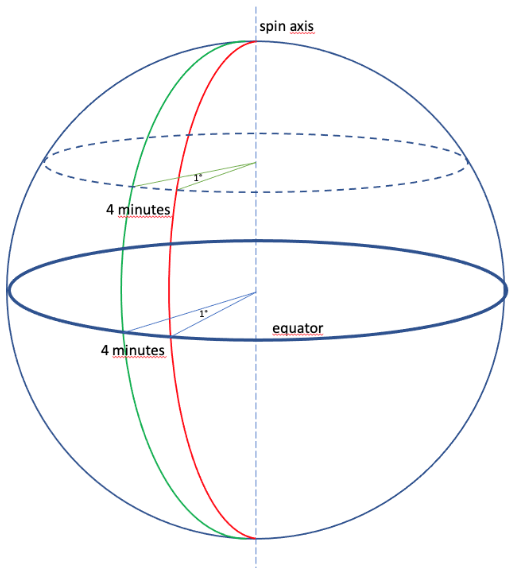

FIGURE 1. The average time required for the Earth to rotate one degree is 4 minutes, based on (1).

Note that the distance between the arcs depends on the latitude, but the time difference remains constant, so the time is identical in positions on a meridian. It is thus sufficient to carry out the planned calculations only for the main equatorial circle, since the local time depends on the longitude only.

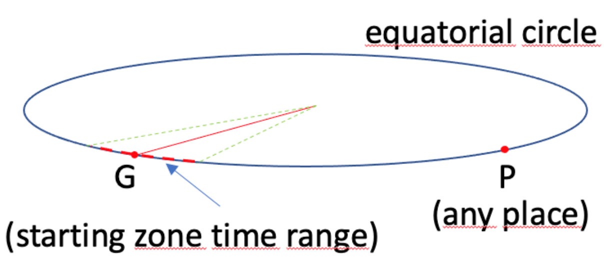

FIGURE 2. Examination of the equatorial circle of latitude, where G is the center of time zone 0 (the prime meridian) and P is any location on this circle of latitude.

Since each time zone includes 1 hour, the equatorial latitude circle is divided into 24 equal parts (±12 parts in practice). In the following, starting from the east longitude value of a location P shown in Figure 2, we determine how many degrees the location of P deviates from the center of the corresponding time zone.

If, for example, the eastern longitude of the point P is K, then it is K degrees away from the starting point G, which can be expressed by the following mathematical relationship:

$$K = n \cdot 15° - 7.5°. \qquad (2)$$

where $n \in \mathbb{R}$ and $-12 \leq n \leq +12$.

The location of the centre of the time zone expressed in degrees (denoted by z) can be determined as a function of K, if we express n from (2) and take its integer part:

$$z = \left\lfloor \frac{K + 7.5°}{15°} \right\rfloor \cdot 15°. \qquad (3)$$

This relation is illustrated in Fig. 3 below.

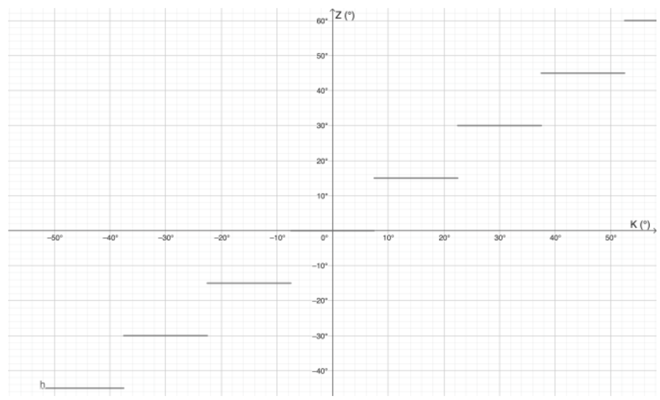

FIGURE 3. Location of the centre of the time zone (z) as a function of K (the graph was created with Geogebra).

With the help of z obtained from the eastern longitude, we already know which time zone we are in. The next step is to determine the deviation (Δ) from the center of the zone in degrees:

$$\Delta = K - z. \qquad (4)$$

From this, we get the modified time, i.e. the solar time (st) by adding the difference (with + or - sign) to the current zone time (i), which is "converted" to minutes, i.e. multiplied by 4 minutes (since 1 degree corresponds to 4 minutes), i.e. 4 /60 (= 240/3600) seconds:

$$st = i + \frac{240 \cdot \Delta}{3600} \qquad (5)$$

In the case of daylight saving time, of course, one hour must be deducted from the time zone. The above calculation is good as an estimate, but not exact, because we assumed an ideal system that did not take into account that:

1. the Earth's orbit is an ellipse, so the orbital speed is not constant,
2. the Earth's orbit (ecliptic) and the plane of the equator do not coincide.

For more accurate calculations, the change in the position of the vernal point and the perihelion, as well as the periodic changes in the Earth's spin axis and rotation speed, must also be taken into account.

It is interesting to mention that four times a year (15th April, 14th June, 1st September, and 25th December) the time difference between the local time and Central Time becomes zero, with the largest difference occurring in November.

To be more accurate, we use formulas from the equation of time [1]:

$$E = 9.87\sin(2B) - 7.53\cos(B) - 1.5\sin(B), \qquad (6)$$

where:

$$B = 2\pi\frac{d-81}{364},$$

E: time difference in minutes
d: calendar day number (see Fig. 4).

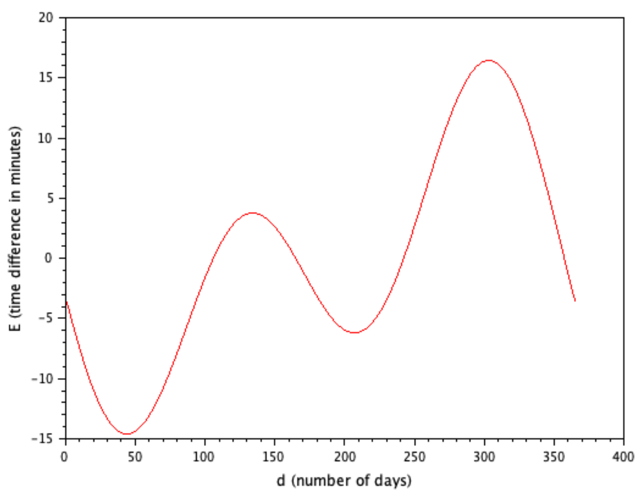

FIGURE 4. Figure made with approximation (6). 4 coincidences (E=0 minutes) per day and the largest deviation (E=16 minutes) as well can be read from the graph.

In addition to determination of the local time, we can also calculate other values, such as solar noon, the Sun's highest position above the horizon, sunrise time, sunset time, length of the day, etc.

An example: determination the solar noon time (c) from the difference between the telephone time and solar time:

$$c = phone\ time - solar\ time = i - st$$

At solar noon, the solar time = 12:00, so: c = (phone time – 12:00),
and hence, at solar noon, phone time = c + 12:00.
Remark: in order to get the HH:MM format, the times in the source code must be converted to minutes and thus calculate their difference, and then convert back to hours and minutes.
Another example is to determine the Sun's highest altitute above the horizon, SHA, from the declination (D):

$$D = -23.45\cdot\cos\left(\frac{360}{365}\cdot(d+10)\right)\cdot\frac{\pi}{180},$$

$$SHA = 90° - L + D,$$

here L = Latitude = 0°-90° North.

The app (for now only in Hungarian) can be downloaded for free here: ***https://suntime.stonawski.hu/***

Advantage of this free application is that it does not take approximate values from tables, but calculates with the local coordinates provided, and in addition to the solar noon, it also gives the altitude of the Sun above the horizon, the sunrise and sunset times, and other information, as well.

III. CHECKING THE CALCULATIONS WITH A SUNDIAL

In order to check the completed app, it is an excellent opportunity for students to activate their relationships, involving their sister schools and sister cities in the measurements. The solar noon calculated by the app allows users to check the time using a sundial and compass (see Fig. 5).

It is worth highlighting that difficulties may arise in the international applicability of the app due to differences in time zones. For example, in Hungary, near the eastern border of the country corrections were necessary due to the time zone crossing (it did not work in Fehérgyarmat by default). For this reason, it is also worth noting that not all countries strictly follow the time zone conventions. China, for example, uses a single time system despite having multiple time zones. One possible direction in the development of the app could be to take into account these special situations, so that the app can be used even more widely all over the world.

FIGURE 5. Checking the solar noon with a home-made "slotted" sundial and a compass.

IV. DIDACTIC APPLICATION

Figure 6 shows a demonstration tool created by a student majoring in physics teaching. In the upper part of the photo, a lamp can be seen that can be moved in a semicircle (made of a bent PE water pipe), illustrating the apparent movement of the Sun, which illuminates a sundial model. Thus, in school education, we can discuss this topic even in classroom settings. In the lower part of the photo, a 3D printed digital sundial can be seen. The time with an accuracy of ±10 minutes can be read here.

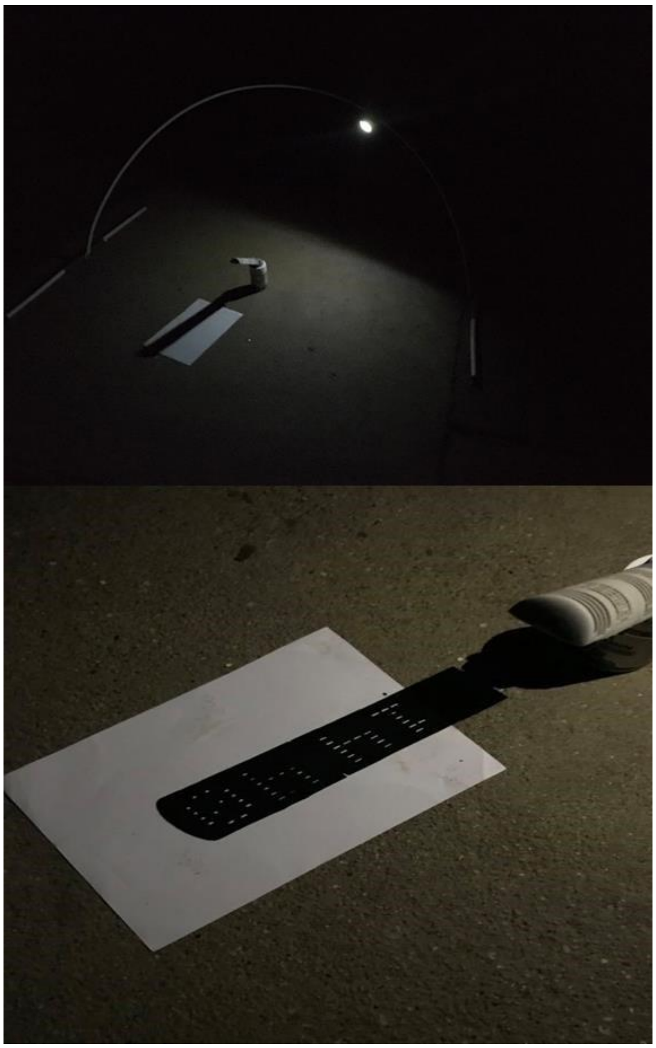

FIGURE 6. A home-made device demonstrating the movement of the Sun, with a home-made, 3D printed digital sundial (upper part). 14:40 can be read in the zoomed-in photo (lower part).

Creating such a device as a school project could also be a good task for students.

V. TECHNICAL APPLICATION

A more detailed knowledge about time shown by the sundial not only broadens the students' view of time, but it can also be used for practical purposes. One such innovation could be the sun tracking in solar panel systems. Nowadays, solar tracking systems allow the solar cells to follow the movement of the Sun, thus making more efficient use of the potential of solar energy, as they always maintain an optimal angle to receive solar radiation. These systems use sensors to detect the position of the Sun [6]. For solar tracking systems, however, cloudy weather is a challenge, as clouds provide temporary shading and can reduce the amount of solar energy. Such systems suspend movement while the weather is cloudy. In this case, the solar panels remain at the last known optimal angle until the clouds disappear and the Sun reappears.

If, on the other hand, the local time and the altitude of the Sun in the sky are permanently known, the best performance can be achieved by properly positioning the solar panels, and the failure of the sensor will not cause any problem. Combined systems can even be created, in which movement according to local time is only activated in case of cloudy weather or in the event of a sensor malfunction. Alternative modes of movement, such as positioning based on local time, can be good additions to sensor controlled systems, especially in areas where weather conditions can be variable or sensor errors are common.

We are currently testing a small solar panel controlled by an Arduino microcontroller, and plan to extend the experiments to more solar panels.

We can present our students an experiential, realistic geometric problem, if we want to calculate how far apart the solar panels should be installed so that they do not shade each other, or only less, and thus operate with the highest possible performance (Figure 7).

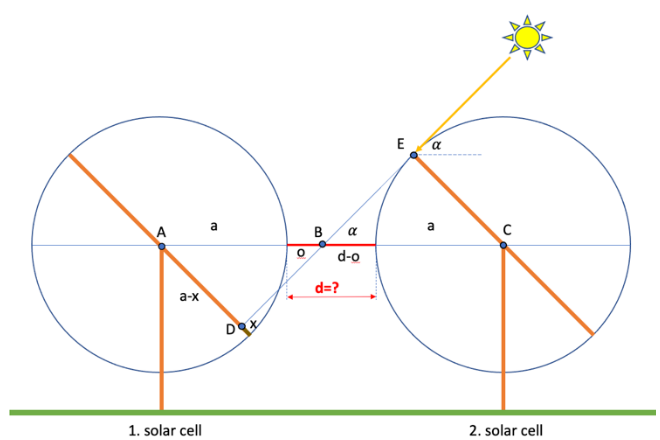

FIGURE 7. Two solar cells (represented by the two orange colored diameters) installed at a distance d from each other are rotated by an arbitrary angle α with respect to the horizontal, during which the solar cell on the right casts a shadow of size x on the left one. Question: at what d will the value of x be minimal, taking into account the optimized space utilization of the solar cells?.

Using the notations in Figure 7, we find the following similar triangles:

$$ADB\Delta \sim BCE\Delta$$

from which the size x of the shadow cast on the left solar panel can be expressed:

$$x = 2a - (2a + d) \cdot sin\alpha,$$

where
x: shadow size
$2a$: the length of the solar cell
d: the distance between the two solar panels
α: the angle of the sun's rays with the horizontal

If the parameters (d, a) in the above equation are given, by changing the angle (between 0-180°) we can prepare the shadow longitude-angle (i.e. x-α) graph, with which we can choose the optimal settings for d (see Fig. 8).

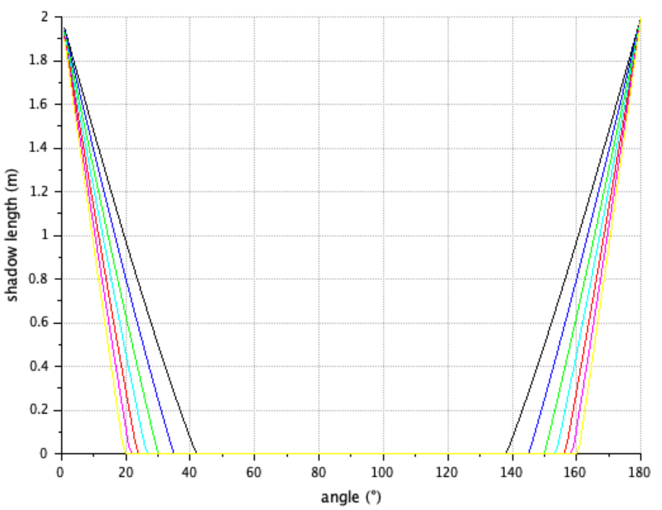

FIGURE 8. The shading of the 2 m wide solar panels for the distances of d=1 m (black line) ... 4meter (yellow line). The two values differ by about 20 degrees in the case without shadow.

VI. LUNAR TIME

Nowadays, establishing an unified time zone on the Moon is a serious challenge for scientists, as it currently does not have an independent time zone. Scientists and space agencies are currently working to reach an agreement on the lunar time zone. The possibility of the new time zone being independent of terrestrial measurements or synchronized with UTC (Coordinated Universal Time) is being investigated. The advantage of an independent lunar time zone would be that accurate lunar time measurement could be ensured even in the event of a loss of contact with Earth. In addition, based on the experience about lunar time, it will be easy to develop similar time zones that can be applied to other planets as well. Because of the gravitational differences between the Earth and the Moon, timekeeping devices operate at different speeds: a lunar timekeeping device runs 56 microseconds faster in 24 hours than on the Earth. Although this difference may seem negligible, it can have a significant impact on the work of astronauts and the coordination of space missions. Installation of a satellite navigation system around the Moon is essential for accurate time measurement and navigation on the surface of the Moon. Its design would be similar to the terrestrial GPS, and according to the plans, it could be operational by approx. 2030. Designating reference points and placing satellites around the Moon would help in accurate time measurement and positioning on the Moon. [7]

VII. CONCLUSIONS

Due to the insistence on the time displayed by the telephone, the concept of real local time has disappeared from people's live. How often do we stop to ask ourselves: when is noon? How many minutes are there as a difference between the eastern and western borders of our country, according to the Sun? How many kilometers do we have to travel to the east in order to make one minute difference between the solar times? The perception of real time extends to details as small as daylight saving time and affects many aspects of our lives.

The app we have developed and the calculations made with it create an opportunity for students to rediscover the solar time, thus improving their concept of time. Students who understand the fundamentals of local time and calculating time zones can make many interesting discoveries. For example, when determining the differences between time zones, they can find out how many kilometers of displacement is necessary to create a given time difference. They can learn about the reasons and effects of daylight saving time, as well as think about what advantages or disadvantages it has for them and their environment.

It is up to the teachers how many interesting and instructive measurements they assign, as well as what questions they ask their students with the help of the app we have developed. Such activities not only deepen students' knowledge of mathematics, physics and geography, but also awaken their curiosity about the temporal dimensions of the world. Through this, students can develop skills that can make them outstanding in the future in terms of global thinking and cultural sensitivity.

ACKNOWLEDGEMENT

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