metrology

Review

Time and Its Measure: Historical and Social Implications

Paolo Vigo [1] and Andrea Frattolillo [2,*]

[1] PALMER s.c.a.r.l., Science and Technology Park of Southern Lazio, 03013 Ferentino, Italy; p_vigo@libero.it
[2] Department of Civil, Environmental Engineering and Architecture, University of Cagliari, 09123 Cagliari, Italy
* Correspondence: andrea.frattolillo@unica.it; Tel.: +39-070-6755265

Abstract: Time and frequency are quantities that have seen a proliferation and diffusion of tools, unimaginable until a few decades ago, and whose application implications are multiplying in a digital society, now characterized by an absolute lack of temporal and spatial limits. Today's world requires a perfect synchronism of human activities, both for the need to identify with certainty the moment of commercial transactions and to accurately describe biological phenomenologies, which affect the social life of individuals to the point of having repercussions on issues such as safety, production and manufacturing organization. In this regard, the recent award of the Nobel Prize for Medicine for the discovery of the gene capable of controlling our internal biological clock is significant. This paper describes the social implications connected to time measurements, analyzing some very original application effects, ranging from the typical cadences of production activities to sports applications, going so far as to highlight its apparent anomaly of adopting, unlike all other physical quantities, duodecimal and/or sexagesimal scales. Real time and perceived time can both converge and diverge, and this is almost never objectifiable, as it varies from individual to individual, according to individual experiences or sensitivities. This paper is a point of reflection attempting to understand how the chronology of major historical events influenced the organization of time as it is known today and how we arrived at actual measuring instruments so accurate and interconnected with the social sphere. The evolution of calendars and instruments for measuring relative time is described in terms of their specificity.

Keywords: time measurement; calendar; relative measurement

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1. Introduction

Time is one of the seven base units of the International System (SI), and the "second" (s) is the unit adopted as the standard for its measurement.

The unit of time was initially defined as 1/86,400 of the average solar day, but the irregularities in the Earth's rotation motion made the definition no longer satisfactory. Therefore, in 1960, the XI General Conference of Weights and Measures (CGPM) adopted a fraction of the time of the Earth's revolution around the Sun in the year 1900 as the unit.

Later, in the XIII CGPM (1967), the "Atomic Standard Time", based on the cesium atom transition between two energy levels, led to the current definition of the unity of time: *the second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between two hyperfine levels of the ground state of the cesium 133 atom.* Basically, when an electron in the *cesium 133* atom passes from one energy level to another, it emits (or absorbs) radiation (a wave phenomenon) with a constant frequency, passing 9,192,631,770 oscillations in 1 s [1]. Other very accurate resonance frequencies are those of *rubidium Rb87* and *hydrogen maser*, as evident in Table 1, where frequencies are compared with those of a mechanical pendulum and a quartz watch.

This definition, as specified in the 1997 CGPM meeting, is based on a cesium atom not perturbed by black-body radiation, a condition that is obtained at a temperature of 0 K (t = −273.15 °C). The frequencies obtained from atomic clocks at room temperature should therefore be corrected for the offset induced by electromagnetic background noise.

Note that, from a metrological point of view, there is no substantial difference between the definitions of "time" and "frequency", which, mathematically, are one the inverse of the other ($f = 1/t$). The time scale is duodecimal with multiples and submultiples, partly sexagesimal and partly decimal (1 h = 60 min = 3600 s ... tenths of s, hundredths of s, thousandths of s). Note again that, with the 2019 redefinition of the SI base units, "time" remains the (maybe the only) fundamental unit in the SI, defined only in terms of physical constants and used in the definitions of the following: in "meter (m)", together with the speed of light in a vacuum c; in "kilogram (kg)", in the "light intensity unit (cd)" and in "Kelvin (K)", together with the speed of light c and the Planck constant h; and, finally, in the "unit of electric current (A)", together with the elementary charge e [2].

Table 1. Resonance frequencies of different sources used for atomic oscillators.

Oscillator Type	Resonance Frequency (Hz)
Pendulum	1
Quartz Wristwatch	32,768
Hydrogen Maser	1,420,405,752
Rubidium	6,834,682,608
Cesium	9,192,631,770

In Italy, the national time scale is made at INRIM by a set of independent cesium atomic clocks and is compared, via satellite, with the time scales of other countries. It is maintained within ±100 ns of the international reference UTC (Unified Time Coordinated). The unit of time is realized with a relative standard uncertainty of 1×10^{-13}. However, the progress of research allows us to have, today, atomic clocks (based on strontium or ytterbium atoms) that are wrong 1 s every 5 billion years, that is, one error in a time greater than the age of the Earth and the solar system (4.5–4.6 billion years).

Time measurements can be relative or absolute. Absolute time is the calendar one, usually linked to historical or religious events to such an extent that, even today, there is no universal time scale because each society has tried to adopt one by imposing it on the others. In the definitions of absolute time, physiologically, there is "an error of zero" due to personal choice (the beginning of creation for Chinese people or for Jewish people), an error that, in the Christian calendar, could be "attenuated", referring not to the birth of Christ (an event that does not find certain references) but to his crucifixion, which instead finds confirmation in the documents of Rome (Pontius Pilate) [3].

Significant is the different perceptions of time expressed by Dante Alighieri in his Divine Comedy when (Purgatorio, canto XVI) one of the angry people (Marco Lombardo, a courtier of his time) addresses him by apostrophizing, "Who are you that our smoke cleaves and about us talk, as if you still divide time by calends?": one dictated by living in the earthly dimension with times and limits dictated by everyday life and the other dictated by living in the dimension of eternity.

In the social sphere, this subjective perception is greatly amplified by the number and the importance of the concrete events that occurred in the particular period under observation. This purely quantitative approach fails to explain why "the human mind tends to attribute an unusual value to any calendar day that is somehow exceptional". Einstein also expressed it very well with his famous statement on perceived time: "Put your hand on a hot stove for a minute, and it seems like an hour. Sit with a pretty girl for an hour, and it seems like a minute. That's relativity." For this reason, it is not generally possible to also transfer the continuity of astronomical time, postulated by Newton, to social time. Critical and significant dates always interrupt this continuity.

Even the so-called "time 0", the arbitrary or non-starting point chosen to compare different events, has always been associated with the date of some historical, civil or religious event, conventionally imbued with profound social implications. Think for example about the following: the death of Alexander the Great (323 BC) or the Battle of Gaza (312 BC) among the Babylonians, the Olympics among the Greeks (776 BC), the founding of Rome (753 BC) and the battle of Anzio (468 BC) among the Romans, the birth of Christ among Christians, the mythological foundation of the Japanese Empire by Jimmu Tenno (660 BC), and the Hegira (the abandonment of Mecca by Muhammad and his transfer to Medina in 622 AD) [4].

The oldest lunar calendar in the world dates back to nearly 10,000 years ago and was found in Warren Field, Scotland. The calendar consists of a series of 12 holes carved into the ground, distributed in an arc over a stretch about 50 m long. The holes, with different shapes and sizes (up to 2 m in diameter) and dug at different depths, had to imitate the shape of the Moon in its various phases, and, if necessary, they could host wooden poles inside. By marking the position of the Moon from time to time, we kept track of the moment of the month in which we were and the flow of the lunar months throughout the year.

Currently, the Western world adopts the Gregorian calendar (Figure 1), which, on the Christian scale, gives the beginning of the world as −2636 years for Chinese people but −3760 years for Jewish people; the founding of Rome as −752 years; the founding of Islam as +622 years; the beginning of the Orthodox calendar as −15 days; etc.

Figure 1. The adoption of the Gregorian calendar, dating back to 1582. The night of Thursday 4 October metaphorically lasted 10 days to recover the delay accumulated in more than 1600 years by the previous Gulian calendar.

In the adoption of this calendar, particularly significant is the cancellation of the days between the 5th and 14th of October due to the "defects" accumulated in the Julian calendar.

Relative time is the measure of a time interval, that is, the duration of an event. Therefore, absolute time presupposes a dating, while the measurement of relative time is independent of the date and time of the event.

The measurement of time intervals (relative time) historically takes place with ever greater precision, starting from the heartbeat frequency used by Galileo to formulate the isochronism law of the pendulum. The latter phenomenology risked becoming a universal metrological reference since, being independent (it depends only on the mass and length of the pendulum itself), it was an alternative to the meter because of its universality and, above all, its greater accuracy.

Currently, relative time measurements show very small uncertainties thanks to the use of resonant quartz, whose technology is now widespread in wristwatches, with typical uncertainties being of the order of 10^{-12} s [1,5].

This paper is a point of reflection attempting to understand how the chronology of major historical events influenced the organization of time as it is known today and how we arrived at actual measuring instruments so accurate and interconnected with the social sphere. The way in which the first time scales varied considerably in different cultures is highlighted, giving strength to a multidimensional, irregular and multidirectional concept of time, but in contrast to the concept of "time continuous and unidirectional" introduced by Christian culture. The inconsistencies related to current time measurements when linked to inaccuracies in the measurement of the space covered are shown, specifically for sports applications, followed by a discussion of the most recent theories that try to discretize time into finite packets, with all the limits connected to the effective measurability of these packets and time's possible interdependence with the proximity and the speed of a massive body.

2. The Social Implications of the Measurement of Time

The first to organize time according to a non-decimal scale was probably the Babylonians, for whom the division of the year was twelve months, due to the twelve phases of the moon, and it was therefore logical to divide day and night into twelve phases of light and twelve of darkness, the twenty-four hours that we know. It is always assumed that the Babylonians decided to divide the hours into sixty minutes and the minutes into sixty seconds because sixty was the largest number that the Babylonians had given a name (the sexagesimal system). The same weekly organization was inherited by the Babylonians and provided a temporal sequence of activities that ended with the last day dedicated to rest. Even today, in the organization of surveillance shifts, the sentries are required to pay attention for 2 h and rest for 4 h in order to ensure the highest degree of vigilance. This organization dates back to Julius Caesar, who spread the use of the hourglass (Figure 2) among the legionaries in order to respect the guards during the long solar hours characterizing (especially in summer) the lands of the Diano valley. The time taken by the water to escape from the underlying hole was the reference time unit. The term hourglass comes from the Greek *κλεψύδρα* (klepsýdra), which literally means "steal-water", since the first models used water for religious and philosophical questions, giving a better idea of the passage of time.

Even the weekly division into quantitatively equal periods is not historically determined by astronomical phenomena but rather associated with events of social aggregation for the exchange of goods. For example, the Roman week was marked by the "*nundinae*" that occurred every eighth day, during which farmers entered the city to sell their products. Similarly, the duration of a week was ten days for the Incas; four days for many tribes in West Africa; five days in Central America [6], the East Indian Archipelago and old Assyria (now Soviet Russia); etc. The cyclical period chosen by ancient populations to divide the lunar month was therefore often connected to economic aspects of daily life. The shorter intervals of three, four and five days are those that guaranteed communities, without large supplies of food or with other needs, a sufficient frequency of supply from neighboring communities. By contrast, the much less common six-, eight- and ten-day longer cycles apparently arose by doubling the previous period whenever a large market was desired for a large area's products.

Those temporal systems that are common among small, closely intertwined groups participating in the same social rhythm obviously become less and less adequate as society expands and widens its field of interaction. In the Western world, the calendar based on the repetition of seven-day periods spread with Rome throughout its empire as early as the first century BC; this time it was its astrological value that decreed its success and made it a universally recognized institution.

Figure 2. Ancient Roman water clock. Note the small holes, indicating the days, and the writings, indicating the months, engraved on the edge.

In 1793, the revolutionary fury of the Enlightenment attempted to overturn this secular organization by introducing the use of the decimal system for the measurement of time. The Council of the French Republic imposed (from 1793 to 1805) a new calendar (Figure 3) with months of thirty days (from Nivose to Frimaire) and weeks of ten days, each of which was divided into two phases of ten hours each, with each hour divided into a hundred minutes of a hundred seconds.

Figure 3. The calendar imposed by the Enlightenment revolution and based on the use of the decimal system for measuring time.

Immediately rejected by popular acclaim, after only two years (1802), by the Cisalpine Republic, both for the suppression of the weekly rest period (many Sundays are lost with

10-day weeks) and in the unnatural denial of circadian rhythms, "*The respect that all the principles command for the customs and habits of the Peoples and for those that affect public worship has restored the use of the common era with the new constitution*" [7].

Clocks with ten-base dials (Figure 4) were immediately eliminated, although in Paris, for many years, a decimal clock remained in operation in the market square. In France, another attempt was made in 1897, when the Commission de décimalisation du temps, created by the Bureau des Longitudes, proposed a compromise of retaining the 24 h day but dividing each hour into 100 decimal minutes and each minute into 100 s. The plan did not gain acceptance and was abandoned in 1900. A similar attempt was repeated in recent times when Marchionne tried to upset working times with a production organization based on only two shifts of ten hours each (very favorable for the employers). But, just as quickly, he was challenged by the trade unions in the FCA factory in Serbia who saw serious risks to the level of attention of workers (and, therefore, to their safety).

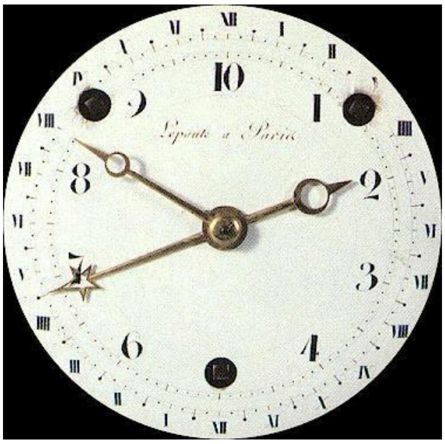

Figure 4. Clock with ten-base dials.

The ability of "social time" to express a greater meaning in the collective perception than the astronomical one, so as to become a reference, is also found in commonly used expressions such as "*immediately after the world war*" or "*see you later the football match*". Similarly, expressions such as "*for a semester*", "*for a working day*" and "*for the duration of Lent*" represent references to generally understandable lengths of time while varying independently of each other, without any mention of astronomical phenomena.

The radicalization of some social customs linked to time can also be found in the summer time convention. The proposal was first advanced in Paris by Benjamin Franklin, one of the American "founding fathers", in his essay *An Economic Project to Lower the Cost of Light*, published in the *Journal de Paris* in 1784, but it fell on deaf ears. It was reconsidered and implemented only in 1916, in wartime, when energy saving became important, not only in the United Kingdom but also in Italy and other European countries. In reality, the desired result, an increase in the number of hours of daylight for leisure and free time, could have been achieved simply by moving the working hours from 8:00 to 4:00 p.m. But the designation "9:00 to 5:00 p.m." has become so deeply ingrained in our economy that it has even been considered preferable to shift the hourly units in the twenty-four-hour cycle.

The existence within the human body of cadences or circadian rhythms has been confirmed by the studies of three US scientists (S. Benzen, J.J. d'Ortus de Marian and R. Konopka) who were awarded the Nobel Prize for Medicine [7].

The problems relating to the measurement of "relative time" are as follows:

- Legal, as commercial transactions require certainty in the determination of time. (In international financial dynamics, electronic transactions that are concentrated in the last seconds of the closing of the stock exchanges require maximum attention!);

- International, as GPS service (Figure 5) is considered "strategic" for governments, so much so that the service connected to the traceability of the signal cannot be interrupted, even in the event of a strike.

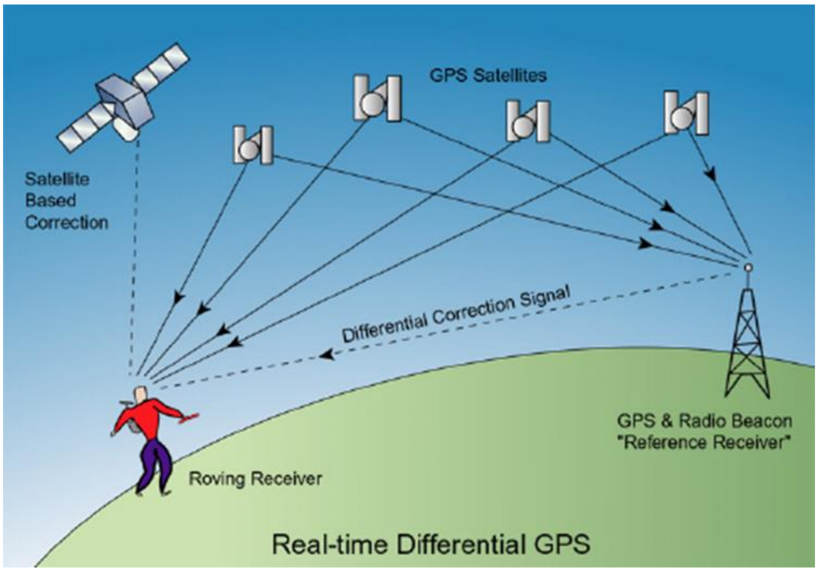

Figure 5. GPS operating scheme: through the signals received from satellites in orbit (at least 4), the terminal is able to calculate its position by knowing the flight time of the signals, the map of the satellites and their time synchronization.

Regarding the first problem, in order to enact an international convention establishing how time should be measured, when the day should begin and end or what length an hour might be, in 1884, the Greenwich meridian was chosen as the prime meridian of the world during the International Meridian Conference. In the late 19th century, 72% of the world's commerce depended on sea charts, which used Greenwich as the prime meridian, and this made it the center of world time. The division into time zones is vital for international organizations, but, sometimes, it risks being compromising due to the operational difficulties that it entails. This is the reason why some countries like China, with extensions covering up to five different time zones, have adopted only one (+8 compared to Coordinated Universal Time). An exception is the Xinjiang region, where two time zones are followed at the same time to optimize commercial activities with neighboring Kazakhstan and Kyrgyzstan, however creating some confusion among the inhabitants.

Regarding the second aspect, the GPS system has now supplanted the navigation systems developed during World War II, when it witnessed a tremendous research and development effort of radar and related techniques. Among the latter, the most widespread was, until the 1960s, the LORAN: Long Range Navigation System [8], which uses the time interval between signals received from three or more stations to determine the correct position. The continuous development of technology made possible today the multi-GNSS (Global Navigation Satellite System) constellations (about 140 GNSS satellites in space in 2020 managed by eight different analysis centers [9]), significantly improving performance, satellite visibility, the dilution of precision, accuracy, spatial geometry, redundancy and reliability [10]. It is significant to underline that, despite the GNSS requiring high-accuracy time information, it is used successfully in many scientific (studies of the Earth atmosphere, snow depth, soil moisture and terrestrial water storage variation) [11] and practical applications (the positioning accuracy of a smartphone), with the advantages of continuous operation, a low cost, operation in all-weather conditions, a high accuracy and a high temporal resolution [12].

Examples of temporal cadences are as follows:

- In juridical practices for Roman law, "*dies a quo non computatur in term*"; for cultures such as Judaism, it is "*the third day He rose again*", that is, from Thursday to Saturday and not "on Sundays";
- The measurement of the average speed with the safety tutors used for road "safety", allowing for the measurement of the crossing times of the coils drowned in asphalt, which, compared with the data relating to distances (fairly precise mileage values), allows one to calculate the average speed (remember that this quantity is not measurable because it is physically inconsistent).

2.1. Engineering Applications

2.1.1. Vehicle Speed Measurement

The speed measurement involves two quantities, namely, space and time, through the following formula:

$$v = \frac{space}{time}\ [\mathrm{m/s}] \tag{1}$$

There are several ways to measure speed:

- Measure space and time;
- Establish space and measure time (fixed goal systems, see Figure 6);
- Establish time and measure spaces both directly and indirectly;
- Measure the effects that speed has on other quantities (for example, frequency).

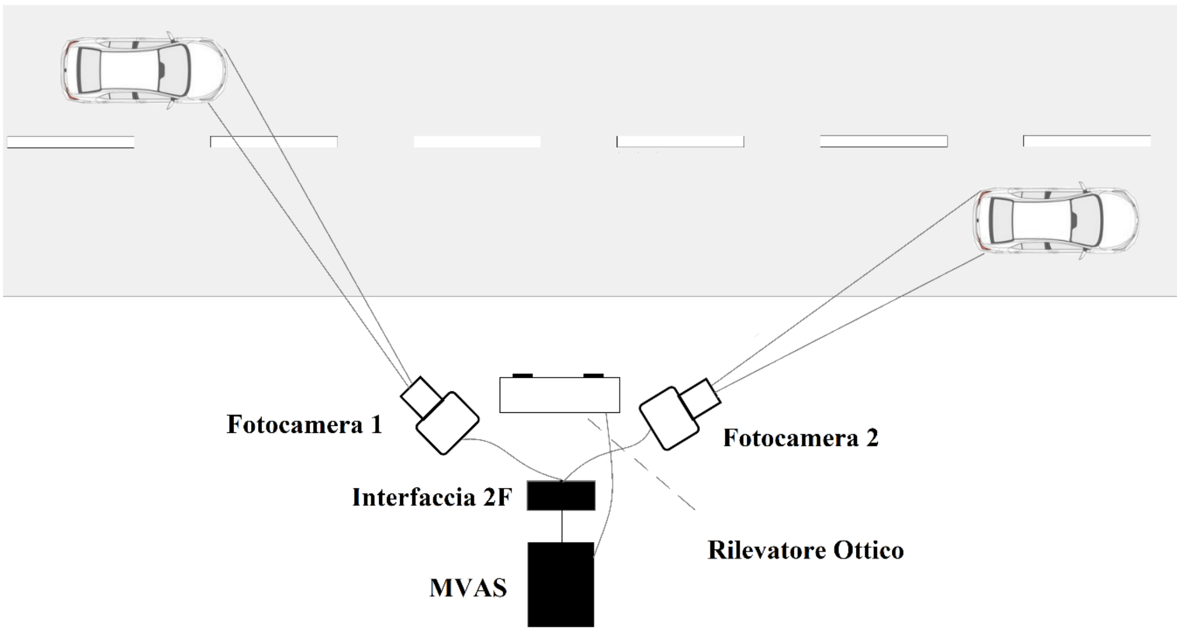

Figure 6. Speed measurement with fixed target system (speed cameras): two photocells detect the time in which a car passes between first and second, determining the speed and photographing the license plate if it is higher than the limit allowed on the road where it is located.

2.1.2. Measuring Instruments with Piezoelectric Sensors

The operating principle is based on the use of three piezoelectric sensors hidden in asphalt and positioned transversely to the road but parallel to each other at a relative distance of 1 m (Figure 7A).

A microchip processes the information detected in the three different measurements made when a vehicle passes over the measuring range in order to determine the speed of the vehicle.

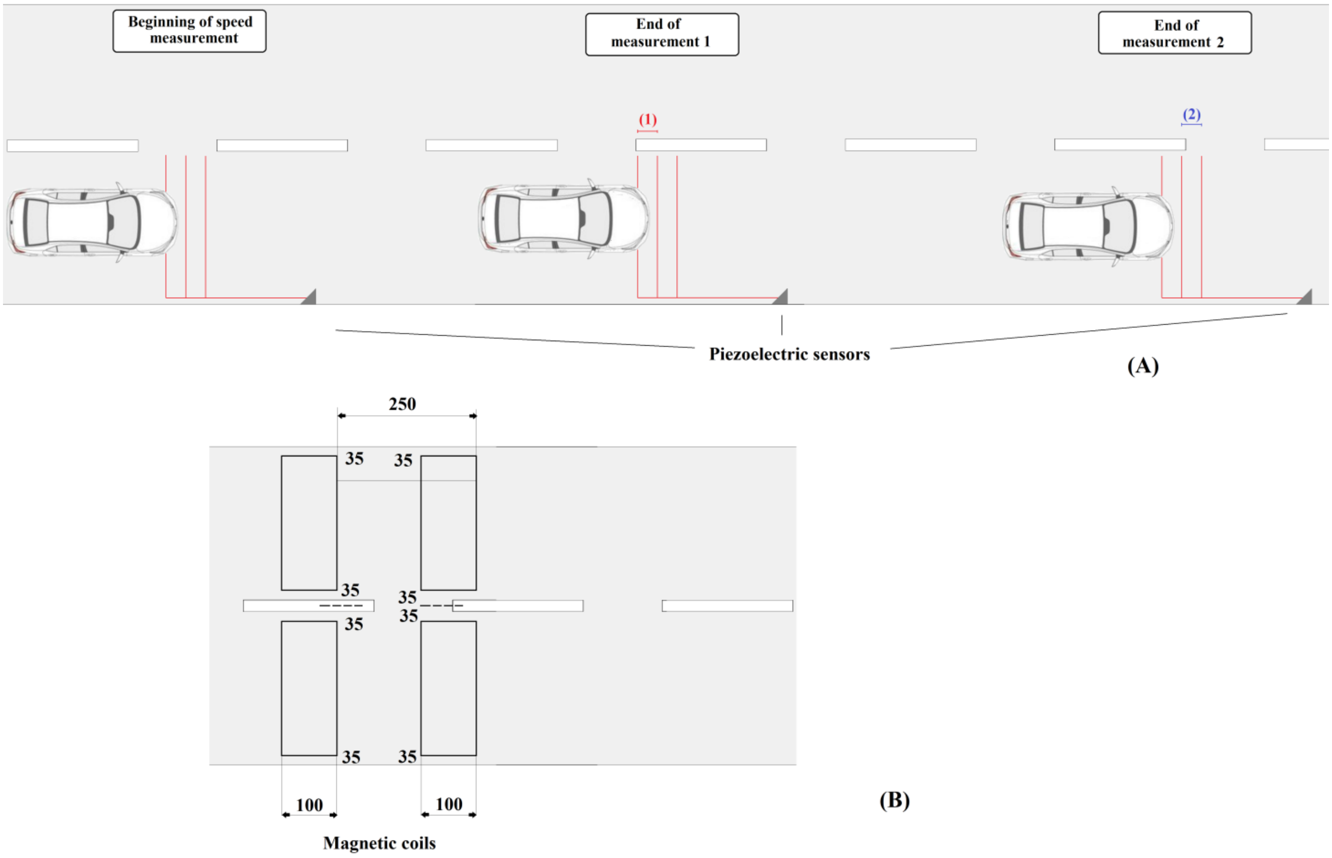

Figure 7. Speed measurement with fixed target system: with piezoelectric sensors (**A**) and with magnetic coils (**B**). Dimensions in cm.

2.1.3. Measuring Instruments with Magnetic Coils

In each lane, two coils are drowned in the asphalt and detect the magnetic fingerprint of the "driver" vehicle that crosses them (Figure 7B).

2.1.4. The Telelaser

The measurements are based on the time of flight (TOF). A series of infrared laser pulses are emitted toward the vehicle (Figure 8). The device reads the echo reflected by the vehicle for each pulse.

Figure 8. Speed measurement with telelaser, which exploits the high-frequency laser emitted in the direction of passing cars, even when they are at a great distance, effectively making useless the braking that many motorists dangerously do when they see a speed camera.

These instruments must be calibrated (i.e., made referable to the SI standards) in Italy according to the sentence of the Constitutional Court of June 2015 [13,14].

Speed cameras, in fact, being instruments used to sanction the exceeding of a limit value in the range of use of 0–230 km/h, in compliance with the European Directive 2014/32/EU, better known as the "Measuring Instruments Directive" (MID) [15,16], must be traceable, with calibration frequencies set by national regulations.

2.1.5. Application to the World of Sport: Tokyo Olympics 1964

In the 100 m freestyle race, two athletes (the German Hans-Joachim Klein and the American Gary Ilman) simultaneously crossed the finish line in 54.0 s. The (unofficial) automatic timing system was consulted to award the bronze. The two had the same time, even to the hundredth of a second, but Klein was one thousandth of a second faster (Klein: 54.060 s; Ilman: 54.061 s). After 35 min of discussion, the judges decided that it was enough, even if the electronic timing was not official, and they gave the bronze to Klein.

Does it make sense to measure time to the thousandth of a second in swimming competitions and use it to determine the rankings and national, continental and world records?

During a 100 m freestyle competition, how much space does an athlete travel in 1/1000th of a second? The space covered by two athletes in 0.001 s is equal to

$$s = v_m \times t = 1.8 \times 0.001 = 0.0018 \text{ m} \cong 2 \text{ mm} \quad (2)$$

where v_m is the average speed of the athlete during the race (that is, 1.8 m s^{-1}, equal to 100 m/54 s), and s is the space covered by the athlete during time t.

The FINA (Federation International de Natation) regulation in force from 2013 to 2017 with respect to sports facilities, particularly swimming pools, states [FR 2.2.1] the following:

> *"Compared to the nominal length of 50.0 m, one tolerance of 0.03 m above and 0.00 m below is admitted on both back walls at any point from 0.3 m above to 0.8 m below the water surface. Such measurements should be certified by an appraiser or other qualified officer appointed or approved by the FINA Member of the country where the pool is located".*

Ultimately, if a tolerance of 0.03 m or 3 cm is allowed in the construction of an Olympic swimming pool, it makes no sense to discriminate the order of arrival of the athletes or the assignment of records with times measured to the thousandth of a second (time taken by the athletes to cover a distance of about 2 mm). In other words, a tolerance of 3 cm between one lane and another means that one lane could be 50.00 m long while another could be 50.03 m long. If the two athletes in the two lanes went exactly at the same speed of 1.8 m/s, they would travel the two lanes in two different times equal to

$$\text{S1} = 50.00 \text{ m};\ v = 1.8 \text{ m/s};\ t1 = S1/v = 27.778 \text{ s}$$

$$\text{S2} = 50.03 \text{ m};\ v = 1.8 \text{ m/s};\ t2 = S2/v = 27.794 \text{ s}$$

Therefore, the two athletes, despite having the same skills (they travel 100 m at the same average speed), take a different time due to the different lengths of the lanes:

$$\Delta \text{t} = \text{t2} - \text{t1} = 27.794 - 27.778 = 0.016 \text{ s}$$

It can therefore be concluded that the quantity being measured is the time taken by an athlete to travel 100 m (50 + 50). This time (i.e., the measurand) has an intrinsic variation (uncertainty) far greater than one thousandth of a second (0.016 s), and this is caused by the imperfect knowledge of the spatial reference (the length of the lane).

These effects are not reduced for "slower" races, i.e., with respect to how much the distance is increased (200 m, 400 m, etc.), since these distances are obtained by covering a 50 m lane several times. We should add that, although it is not easy, for the two outermost lanes, the effect of viscosity linked to the presence of the side walls, which, with their "boundary layers", slow down the two athletes who travel along these lanes, should be taken into account.

It is questionable whether the phenomenologies considered negligible, such as the temperature of the water (variation in viscosity), can instead influence the records and should be appropriately codified (the use of swimsuits with materials that try to "imitate" shark skin or one-piece swimsuits that favor the reduction of aerodynamic drag is widespread among swimmers), for example, by introducing corrective coefficients as occurs in regattas for different hulls.

3. Evolution of Clocks

Time measurement systems have always reflected the social activities of the community. Among primitive peoples, the alternation of day and night, the changes in the moon and the seasons formed the basis of their systems. To record the course of the seasons, they considered the budding, flowering, falling of leaves and bearing fruit of vegetation and the mutation, migration and mating of animals and birds. In the same division of the day, many tribes recognized four diurnal periods: the rising of the sun, the setting of the sun, noon and midnight. Social considerations entered the judgments of time on which the relative values of temporal durations then depended: quantitatively equal periods of time were made "socially" unequal, and, vice versa, unequal periods were socially equal.

In modern times, the need to measure relative time, as required by technology and social organization, is increasingly widespread in social classes, so much so that, today, every individual is able, either with watches or through digital means, to know exactly both the absolute and relative time. Clocks, in their historical evolution, were initially limited, especially in the first centuries, to the classic sundials, which, in public places, allowed one to "follow" the trajectories of the Sun giving "spannometric" indications about time (ten minutes of uncertainty was typical).

Sundials found competitors in the more precise hourglasses (water or sand), but these were less suitable for providing absolute data. It was only later (15th century) that water clocks (Figure 9), based on the laws of hydrodynamics, were developed, of which some admirable monumental applications remain.

Even if they could not guarantee small-sized models, they found applications in the definitions of well-defined time intervals, such as "the times of love" available for customers, and they accounted for thoroughly perforated basins filled with water [17].

In a second moment, around the XXVIII century, mechanical watches were established. Always based on pendulum-like phenomenology, they gradually became less bulky thanks to the making of the first stackfreed, a dispositive able to equalize the varying force of the mainspring in the course of its unwinding (early clocks and watches slowed down drastically during the clock's running period as the mainspring lost force, causing inaccurate timekeeping) [18].

The first pendulum clock, regulated by a mechanism with a "natural" period of oscillation, was made by Christiaan Huygens in 1656. Huygens' pendulum clock had an error of less than 1 min per day, and its subsequent refinements have reduced the errors of his watch to less than 10 s a day. However, no device could keep accurate time at sea until John Harrison, a carpenter and toolmaker, perfected the techniques for temperature compensation and found new ways to reduce friction. In 1761, he built a marine chronometer with a spring escapement and balance wheel that kept the time very accurate. With the final version of his chronometer, which looked like a large pocket watch, he was able to determine the longitude to within half a degree. His fame was overshadowed in 1921 with the invention of the first Shortt–Synchronome named after its inventor, British railway engineer William Hamilton Shortt [19]. The basic idea was to eliminate the interference factors on the pendulum, making it in an invar alloy to reduce thermal expansion and leaving it free to oscillate in a copper tank in which a vacuum was created (about 30 mmHg) to reduce aerodynamic resistance. The further disturbance caused by the link to the clock's mechanism (the main cause of error in precision clocks of the early 20th century) was eliminated by decoupling the two mechanisms and using an electromagnetic system to supply power pulses to the two pendulums (Figure 10).

Figure 9. Water clock made in 1867 by Father Giovanni Battista Embriaco and currently exhibited in Villa Borghese in Rome. The movement of the clock hands is caused by the oscillation of two rods connected to two leaf-shaped basins, filled alternately by a jet of water.

Figure 10. Shortt clock in US National Institute of Standards and Technology Museum, Gaithersburg, Maryland. The primary pendulum (on the left, in its copper vacuum tank) and the secondary pendulum (on the right, linked to the clock mechanism) were synchronized by electro-mechanical means.

Since the 1950s, wristwatches have increased their reliability thanks to the automatic winding obtained by means of a flywheel rotated by wrist movements. Currently, the rapid development of resonant quartz technologies makes it possible to have, at affordable prices, a watch with uncertainties of the order of 10^{-12}, which can also be powered only by solar energy (the phenomenon of resonance by its nature does not require much energy), with the possibility of comparing one's own data, both relative and absolute, with those of the samples of the various primary metrological institutes, through a direct connection with them.

4. Conclusions: Physical Time and Perceived Time

From the above, it is clear that, behind the temporal organization of a society, typical cadences and/or times of human phenomena are always involved, but it is often appropriate to take into account the "perceived time" and its perceptual implications.

The first to address the problem, in the wake of Platonism, was Saint Augustine, for whom time does not exist in itself but is due to the gradual way in which humans learn things. It exists and is perceived differently in relation to the limitation of humans who need time and space to increase their knowledge.

From an engineering point of view, the different perceptions of time between individuals is like measuring the same distance with an elastic material that has a different Young's modulus from individual to individual, and for the same individual according to their mood.

While relative time and cadences always have a rhythm, in the case of emotions or pain, the scale varies, at least by deleting or limiting negative events by slowing down the above-mentioned circadian rhythms.

The following are good examples:

- The paradox of Achilles and the turtle (never reached by Achilles!);
- The immeasurability of the average speed (safety tutor);
- Slowdown or time inversion, which the theory of relativity provides.

Similarly, in the perceptive field, the "synchronicity of an event", or the feeling of "having already experienced it", as well as its "foresight", is an event accepted by psychologists [20,21].

> *In short, the passage and the measurement of time, are only order schemes of space-time with a Euclidean interpretation of everything flowing, opposed to a Platonic interpretation (different scenarios on which the mind projects events).*

Newton's formulation of the concept of "uniform, infinitely divisible and continuous" time probably constitutes the most definite affirmation of the objectivity of time, that is, of it being "equal for all, marked by clocks or by the calendar". Alongside this "objective" definition, there is also a "subjective" evaluation of time, perceived differently by each person and, above all, differently from the astronomical one.

In this regard, it is impossible not to consider that, according to quantum theory (recognized as the most correct and accurate model of the universe), the probability that time too is made up of quanta (discrete and indivisible packets) and not a fluid and continuous quantity, as generally perceived, is inextricably linked to the current and future realistic limits of its measurement. The latter is estimated to be equal to the Planck time (about 5.39×10^{-44} s) in theoretical physics, much shorter than the *chronon*, suggested by H. Margenau in 1950 and revived in the Caldirola model [22,23], equal to about 6.27×10^{-24} s.

It should also be highlighted how the diffusion of technology has led back to or seems to want to lead the perception of time back to the achievement of a result or the achievement of a goal, rather than to strict compliance with a predetermined time. Think of the work environment: in this system, the quantification of time has always been based on the hours worked. The advent of the Internet has produced an apparently positive change by introducing the concept of *Smart Working*, a method of execution of the subordinate employment relationship characterized by the absence of time or spatial constraints and organization by phases, cycles and objectives, established by an agreement between employee and employer. It therefore represents a new managerial philosophy that should (?) help the worker to reconcile the times of life and work and, at the same time, to promote the growth of their productivity.

In conclusion, we cannot fail to consider that, according to modern physics, what has been stated so far is all part of an illusion. Albert Einstein, with his relativity, suggested how time flows differently according to the position of a body, in relation to the proximity to a massive object and to its speed. The faster a body is, the more, for the observer who is attached to it, time expands and space contracts. Therefore, since time and space are both influenced by the speed of the body, it is possible to believe that they are connected to each other and can change according to the circumstances and the reference system. For Einstein, space and time cease to be two distinct variables; they are united in a continuum called space–time (today, chronotope), and each event is identified in a four-dimensional space: the classic three spatial dimensions (x, y, z) and time t. More than 100 years after the formulation of his theory, scientific discoveries continue to follow one another that prove its validity.

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