# Meridian Calibration and Spatial-Temporal Reference Frames for the “Aula della Meridiana” of University of Genoa (Italy)

Ilaria Ferrando, Walter Riva, and Domenico Sguerso

## Abstract

The meridian located in the “Aula della Meridiana” of the historic Rector’s Palace of the University of Genoa, realized in 1771 by François Rodolphe Corréard, represents a rare historical gnomonic hole meridian in Liguria region (Italy). Recent observations revealed an anticipation of approximately 35 seconds in the Sun’s transit compared to the expected time, motivating a comprehensive geomatic survey. This study combines GNSS, total station, and terrestrial laser scanner surveys to accurately reconstruct the room and the meridian line, linking internal features with the external reference system. Data processing included reference frame transformation and computation of the theoretical gnomonic hole position based on solstice and equinox points. The present study approaches the effectiveness of integrated surveying techniques for investigating historical meridians. Indeed, results highlighted discrepancies between the actual and theoretical setups: the gnomonic hole is shifted +7 mm eastward and −34 mm downward, the meridian line exhibits an azimuthal deviation of +31 mm eastward between its extremes, separated by a distance of 5.526 m, and floor non-planarity produces a −17 mm height difference between solstice points. While reference frame transformations proved negligible effect, the construction, restoration, and architectural factors mainly contribute to observed temporal shifts in Sun transit.

## Keywords

3D laser scanner survey · Gnomonic hole meridian · GNSS topographic support · Meridian restoration · Reference frames transformation

## 1 Introduction

By the mid of 18th century, accurate clocks become common among the Italian nobility, making traditional sundials inadequate for their calibration. The adoption of European time, more precise and standardized than the Italian system used in Genoa (Italy) until 1771, renewed interest in *camera obscura* meridians for clock adjustment (Balestrieri 2000). A *camera obscura* meridian, or gnomonic hole meridian, consists of a meridian line, an indoor north–south line, where the sunlight coming from a narrow opening is projected. Figures 1a–d represent how the *macula*, i.e., the projection of sunlight, appears on a set of representative samples of meridian lines across Italy: “Aula della Meridiana”, Palazzo Balbi in Genoa (Lamera and Pigafetta 1987), Santa Maria degli Angeli in Rome (Sigismondi et al. 2025), Duomo di Milano in Milan (Ferrari da Passano et al. 1976), and Duomo di San Petronio in Bologna (Paltrinieri 2007), respectively.

In 1771, the Jesuit mathematician François Rodolphe Corréard (April 25, 1725–October 3, 1794) contributed to the realization of a marble and brass meridian line set into the floor of the “Aula della Meridiana” in the University of

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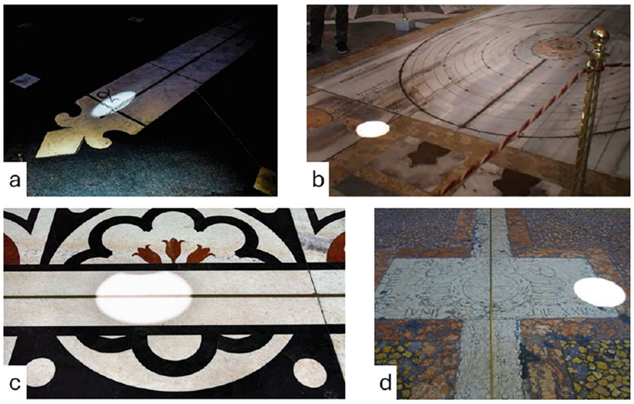

**Fig. 1** Projection of sunlight on several meridian lines across Italy: (**a**)"Aula della Meridiana", Palazzo Balbi (Genoa), (**b**) Santa Maria degli Angeli (Rome), (**c**) Duomo di Milano (Milan), and (**d**) Duomo di San Petronio (Bologna)

Genoa Palace, which is the only potentially functional historical meridian line of this type in Liguria Region (Balestrieri 2000). The "Aula della Meridiana" meridian is one of the shortest solar meridian in the world and it was intended by Corréard as a prototype for another meridian line, that was never built. It has been recently maintained reconstructing the gnomonic hole position, that was missing at the time of its restoration, based on the site latitude and the meridian line length (Càndito 2024). More recently, observations on local noon measured in respect of a reference clock showed anticipation of approximately 35 s with respect to the expected time of *macula* appearance on the meridian line. Figures 2a and b depict the onset and the conclusion of Sun transition on the "Aula della Meridiana" meridian line, respectively. The duration for crossing the entire meridian line, spanning 23 cm, is about 14 minutes. The observed anticipation of Sun transit led to reflect on both the geometrical and the temporal uncertainties that can lead to that time shift, e.g., incorrect meridian line tracing, erroneous gnomonic hole placing, reference system issues, differences in time frame. To analyze the causes of the observed temporal shift, a Global Navigation Satellite System (GNSS) survey in Network Real-Time Kinematic (NRTK) mode was carried out, integrated with total station topographic support, and complemented by a laser scanner survey of the entire "Aula della Meridiana". The laser scanner survey enables the 3D reconstruction of the room and can highlight irregularities on the floor surrounding the meridian line. The topographic support allows to connect the room interior and the outdoor environment, thanks to the topographic network set on external points surveyed by GNSS, enabling the computation of the meridian line azimuth. The present work is an occasion to reflect about the spatial-temporal reference frames joining the external and the internal environments of "Aula della Meridiana", and to show how the in-depth knowledge of the geometry can reveal essential aspects for a rigorous investigation of the problem (Baiocchi et al. 2025).

The paper is structured in the following sections: Sect. 2 explores the causes of differences between true solar time and average time, the survey of "Aula della Meridiana" is described in Sect. 3, whereas the data processing is presented in Sect. 4. The geometric outcomes from the survey are exposed and discussed in Sect. 5. Conclusions and future developments conclude the paper in Sect. 6.

## 2 True Solar Time and Average Time

The moment when the Sun crosses the south, the so-called "true noon", does not occur at 12:00 on our clocks. This discrepancy is caused by several factors, in particular:

- the adoption of daylight saving time from late March to late October, that shifts clock time forward by one hour;
- the establishment of the time-zone system and the adoption of the Greenwich prime meridian, formalized in October 1884 at the International Meridian Conference in Washington. This implies that, within each of the 24 time zones, the time of the zone's central meridian is adopted as the conventional civil time. In Central Europe, civil time is referenced to a unique zone, whose central meridian lies at 15° east of Greenwich. As a consequence, Genoa meridian at 8° 55' 35.4" experiences a time offset of 24 minutes and 17.6 seconds (the so-called "local constant") between solar noon and the solar transit;
- the application of the equation of time (Fig. 3), namely the difference between true solar time and mean solar time. This discrepancy arises because the Earth orbits the Sun at varying speeds as its distance from it changes throughout the year. These variations in orbital speed cause the Sun successive meridian transits to occur slightly earlier or later each day, by up to about 21 seconds in advance or 29 seconds in delay. The equation of time also takes into account the deviations of the track of the Sun from

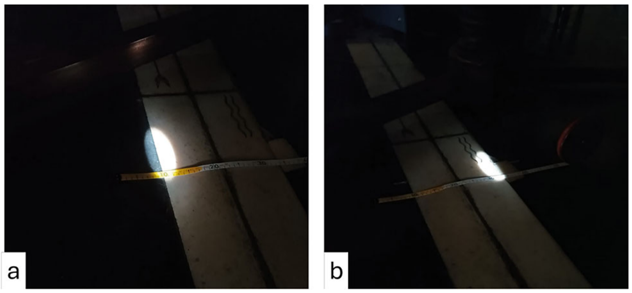

**Fig. 2** Starting (**a**) and ending (**b**) moments of the transition of the *macula* on the "Aula della Meridiana" meridian line

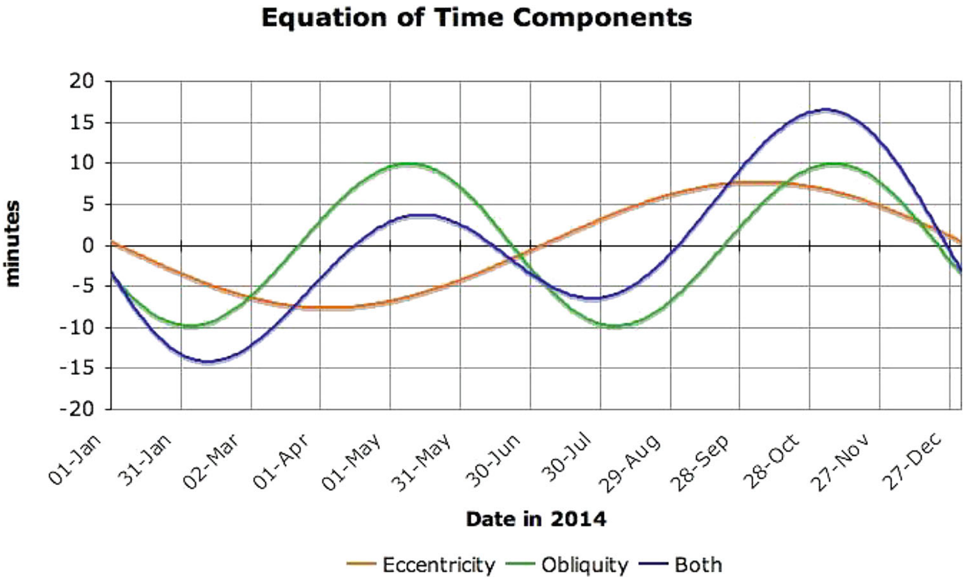

**Fig. 3** Equation of time components: eccentricity (orange), obliquity (green) and resultant (blue). https://aa.usno.navy.mil/faq/eqtime

the celestial equator throughout the year. Although daily differences are small, they accumulate into yearly discrepancies of several minutes. Furthermore, the introduction of the concept of the "mean Sun", an imaginary Sun that always lies on the celestial equator and moves along it at a constant speed, was adopted to simplify timekeeping with constant-rate clocks such as pendulum clocks. This convention introduces additional differences which, when combined algebraically with those arising from the Earth's variable orbital speed, produce an annual maximum delay of 16 minutes and 25 seconds (late October to early November) and a maximum advance of 14 minutes and 15 seconds (early February).

## 3 Survey of "Aula della Meridiana"

The survey of "Aula della Meridiana" room took place on November 25, 2024 (Day of Year, DOY, 330/2024) employing the following survey techniques: GNSS, total station and laser scanner. The employed GNSS receiver is Stonex S850+ in NRTK mode, with differential corrections provided by Regione Liguria GNSS positioning service[1] in ETRF2000-2000.8 reference frame. Three points on the roof of the nearby Santi Vittore e Carlo church were surveyed (points A, B and C in Fig. 4), as external reference. Leica TCR 703 total station was used in two station positions (1000 and 2000 in Fig. 4), connected through forced centering. From station 1000 the same three points already measured with GNSS were surveyed. Four representative points directly around the gnomonic hole border (in up, right, down and left positions) and seven points along the meridian line, marking the dates of the Sun entry into the zodiac signs, were surveyed from station position 2000.

Moreover, a few targets were placed in the room and surveyed with total station to geo-reference the laser scanner survey. The total station survey outcomes served to assess the alignment of points along the meridian line, the alignment between the meridian line and the gnomonic hole, and to connect the external and internal (local) reference systems.

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[1] https://geoportal.regione.liguria.it/servizi/rete-gnss-liguria.html

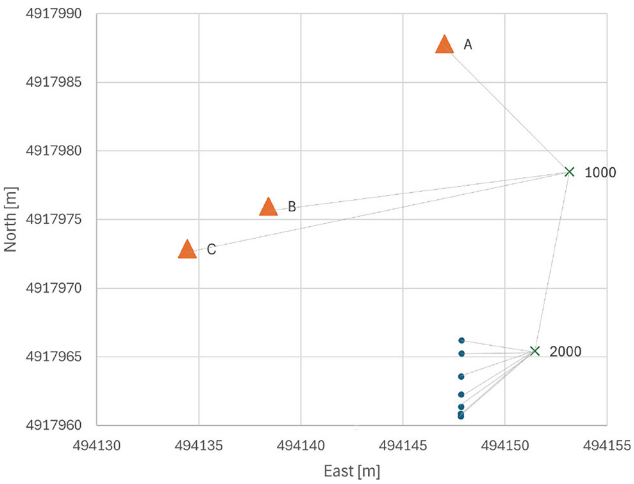

**Fig. 4** Total station positions (1000 and 2000), indicated as black crosses, and surveyed points. Points A, B and C (red triangles) are the three external reference points surveyed on the roof of Santi Vittore e Carlo church, whereas the blue points are the significant points (dates of the Sun's entry into the zodiac signs) along the meridian line. The coordinates are expressed in ETRF2000-2008.0 reference frame projected with UTM 32N cartographic projection

Finally, the Z+F Imager 5006h (Zoller and Fröhlich) terrestrial laser scanner was employed to obtain a 3D survey of the entire room, with particular attention to the floor to assess its planarity and horizontality.

The integration of these three techniques guarantees the completeness of the survey and the link between the internal and the external environments.

## 4 Data Processing

The coordinates of all the points surveyed with total station were computed with the SierraSoft Topko 2011 software package in a local reference frame, then transformed to ETRF2000-2008.0 with UTM 32N cartographic projection with a rigid roto-translation based on least-squares adjustment on A, B and C points, surveyed with GNSS technology obtaining maximum residuals of 2 mm. To get a single pair of coordinates representing the center of the gnomonic hole, the coordinates of the four points surveyed direclty around it were averaged in horizontal and vertical directions.

Time measurement is based on the nominal WGS84 (G2296) reference system, which provides the official time scale used to apply the time equation. A reference frame transformation was performed to assess its influence, taking into account that WGS84 realizations are coincident with ITRF2020 at the sub-centimeter level.[2] The ETRF2000-2008.0 ECEF coordinates (X, Y, Z) were transformed to ITRF2000-2008.0[3] considering 1998–2018 and 2018–2022 velocities lower than 1 mm/yr for GENO station ($v_x$ = −0.7 mm/yr, $v_y$ = −0.1 mm/yr, $v_z$ = −0.8 mm/yr).[4] Then, the transformations from ITRF2000-2008.0 to ITRF2020-2008.0, and to ITRF2020-2024.330 were conducted with the same tools and criteria. Finally, the coordinates of the surveyed points referred to ITRF2020-2024.330 were converted to (ϕ, λ, h), and consequently projected with UTM 32N cartographic projection for easing the following computations.

To calibrate the meridian, the computation of the theoretical position of the gnomonic hole is based on the scheme reported in Fig. 5, where the Solstice and Equinox points are significant points in the meridian line corresponding to the position of the Sun transiting South in those peculiar moments of the year, the co-latitude is the 90° complement of the latitude, $\delta$ is the declination (Pagliano et al. 2017). Knowing the distance between Solstice and Equinox points, the gnomonic hole position can be computed straightforwardly.

Regarding laser scanner data processing, thanks to the presence of targets, the acquired point cloud was registered in the same reference frame as the surveyed points using Z+F LaserControl software package, obtaining a global residual on the alignment points of 4 mm, that not involve the meridian line but only the surrounding environment.

## 5 Results and Discussion

The outcomes deriving from the processing of the acquired data suggest that some constructive elements of the

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[2] https://earth-info.nga.mil/php/download.php?file=WGS84(G2296).pdf

[3] https://epncb.oma.be/_productsservices/coord_trans/

[4] https://epncb.oma.be/_productsservices/coordinates/crd4station.php?station=GENO00ITA

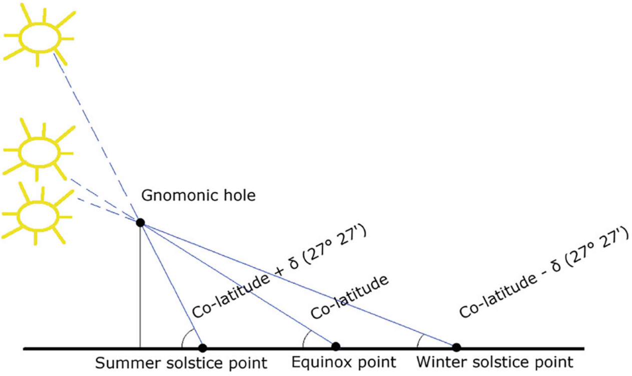

**Fig. 5** Scheme for computing the theoretical position of gnomonic hole based on meridian line latitudes of solstice and equinox significant points

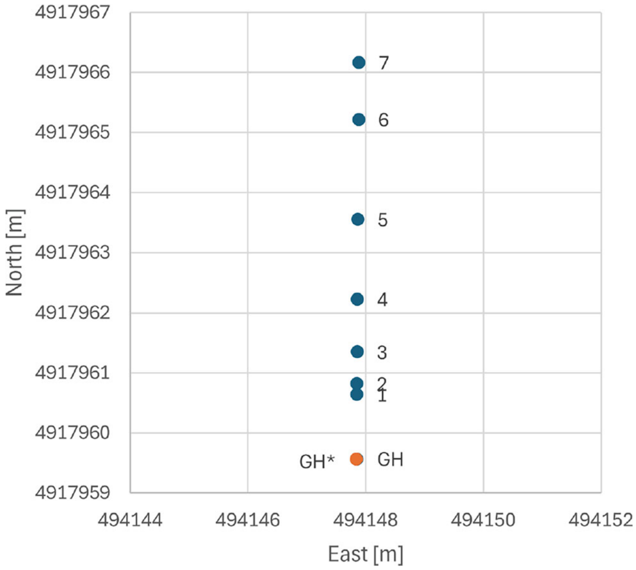

**Fig. 6** Points along the meridian line (1–7, in blue). The gnomonic hole actual and theoretical positions are indicated as GH and GH*, respectively. The coordinates are expressed in ETRF2000-2008.0 with UTM 32N cartographic projection

gnomonic hole and the meridian line differ from the expected setup, based on the theoretical position computation of Fig. 5. In particular, the planimetric and altimetric positions of the gnomonic hole are shifted of $+7\,mm$ (in east direction) and $-34$ mm (downward), respectively. Moreover, an inclination can be appreciated on the global alignment of the meridian line with the north direction, corresponding to a planimetric shift of $+31$ mm (eastward) between the winter and summer Solstice points, represented as points 7 and 1 in Fig. 6, respectively, separated by a distance of 5.526 m.

Nevertheless, the points along the meridian line are properly aligned, forming a straight line with deviation of less than 1 mm from their theoretical positions along the line connecting them. The planimetric misalignment between the gnomonic hole and the meridian line produces an anticipation in the expected time of Sun culmination, that will need to be monitored over the year to quantify its effects. The erroneous altimetric position of the gnomonic hole causes an alteration of the Sun projection along the meridian line, thus producing a shift in the date rather than an effect of anticipation on the starting time of appearance of the macula on the meridian line.

The global non-planarity and non-horizontality of the floor and, consequently, of the meridian line emerged from the laser scanner survey, with a difference in height between summer and winter solstice points (points 1 and 7 in Fig. 6, respectively) of $-17$ mm. In this regard, attention should be given to the effects of ground settlement induced by natural or anthropic causes over the past three centuries.

The performed transformation between the ETRF2000-2008.0 and WGS84 (G2296) reference systems, referred to the epoch of the survey, produces negligible differences (in the order of $+0.032''$) in terms of longitude between the first and the last point of the meridian line, that can be considered a second order effect.

## 6 Conclusions and Future Developments

The survey of the “Aula della Meridiana” at the University of Genoa Palace proved to be essential for investigating the causes of the observed anticipated Sun transit. Thus far, the main possible explanations can be grouped in three categories: (1) construction errors, like the planimetric inclination of the meridian line with respect to true north; (2) natural and human-induced effects, especially for the floor planarity and horizontality; (3) restoration errors, as the misplaced position of the gnomonic hole post-restoration. Whereas, spatial and temporal reference frame transformations can be correctly applied, with negligible residual effects. As a prospective development, a quantification of the temporal effects of the individual aspects identified during the survey will be carried out. Moreover, the gnomonic hole will be restored, both planimetrically and altimetrically, through proper design and implementation. Finally, monitoring the sunlight position at local noon in respect of a reference clock, considering the 3D model of the surface where the meridian line is monumented, can provide additional observations of the phenomena throughout the year, potentially allowing the formulation of relations to correct the temporal shift.

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