Jantar Mantar Observatories as Teaching Laboratories for Positional Astronomy

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The four extant Jantar Mantar observatories at Delhi, Jaipur, Ujjain,and Varanasi have tremendous potential as teaching laboratories of positional astronomy. They could be utilised in this direction in their current state, but this possibility would be considerably enhanced when all the necessary restorations are undertaken, interpretation centers are in place at all the observatories, and there is a continuous presence of astronomy educators, amateur astronomers, and students undertaking observations with these intriguing and user-friendly instruments. Student usage and calibration of the instruments at the Delhi observatory in particular, where the markings are mostly absent from every instrument, has allowed a greater appreciation of the possible construction details of these gigantic instruments. Templates for restoration and also for continuous maintenance of the instruments, are emerging from these efforts.

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Introduction

The instruments of the extant Jantar Mantar observatories at Delhi, Jaipur, Varanasi, and Ujjain have tremendous potential for a user-friendly teaching of positional astronomy to interested students. The observatories also function as a very aesthetic architectural presence that could allow the daily visitors to easily understand and appreciate some basic astronomical observations [1, 2]

This usage could proceed, notwithstanding the fact that most of the markings on the Delhi instruments are missing, and the instrument surfaces have patchy layers. This was achieved using information about the overall dimensions and geometry of the instruments, and tape measure for measuring required lengths on

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the instrument surface to the shadow, or the eye position for night time observations. The fact that the astronomical instruments at the Delhi observatory are still in a usable condition for public utility, has been shown from the work done by the team of observers led by Nehru Planetarium, New Delhi [3].

There is an ongoing process for the functional restoration of the Jantar Mantar Observatory instruments. One aspect that has been of primary importance while looking into the restoration of the observatory instruments has been, recording the present status of the instruments, before the restoration process is undertaken. This is being done through measured drawings, photographs, and tracing the remnants of instrument surface markings by the various teams involved [4]. The positional astronomy observations being undertaken by student groups also serve as a record, even if partial, of the status of the instruments at this time [5].

This database of observations also highlights sections or segments of instruments where there are specific concerns regarding accuracy in the construction or earlier restorations. For instance, observations taken with the Jaiprakas Yantra of the Delhi observatory show systematic errors in altitude measurement, which could be arising from a variety of causes, one of which may be departures from sphericity of the masonry bowls, which constitute the Jaiprakas Yantra [6].

On the other hand, through a database of observations collected, using the cylindrical Ram Yantra of the Delhi observatory [7], it is seen that the instrument, whose original least count was 1 degree, is capable of achieving about 0.1 degree accuracy in measurement of altitude and azimuth. No departures from the intended geometrical construction in implemented masonry have been noticed in these observations.

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The Jantar Mantar observatories consists of a variety of ingeniously constructed positional astronomy instruments, so that, the instruments gives a feel of walking through spherical trigonometry. In the following sections, some of these instruments are discussed, along with a description of observations recorded by student groups, and conclusions derived from the same.

Equinoctial Sundials of the Jantar Mantar Observatories

Participants in outreach activities with these instruments at Delhi and Jaipur : Anurag Garg, Arpita Pandey, Ramesh Chikara, K S Balachander, Dayal Singh, Vikrant Narang, Sneh Kesari, Vidur Prakash, Ruchi Kaushik, Pritpal Kaur, Vidushi Bhatia, Chander Devgun, Chandrakant Misra, Ajay Talwar, O P Gupta, Guntupalli Karunakar, Naveen Nanjundappa, Naresh Kumar, Haran, Munish Lagad, Anees Hasan Siddiqui, Varun Maheswari

The Samrat Yantra, present in all the Jantar Mantar observatories, is the best known of all the 'equinoctial' or 'equal hour' sundials in the observatory. Other examples of equal hour time measurements in the observatories are the Nadivalaya Yantra, and time measurement in the bowl of the Jaiprakas Yantra.

The Samrat Yantra (*Figure* 1), present in all the Jantar Mantar observatories, is the best known of all the 'equinoctial' or 'equal hour' sundials in the observatory. Other examples of equal hour time measurements in the observatories are the Nadivalaya Yantra, and time measurement in the bowl of the Jaiprakas Yantra.There are two Samrat Yantra instruements in the Jaipur and Varanasi observatories and one each at Delhi, and Ujjain observatory. The triangular central wall of these instruments is oriented such that it points towards the north celestial pole. The angle in the right angled triangle is supposed to have been made equal to the latitude of the observatory location, making the inclined wall parallel to the axis of rotation of the Earth. A section of the Misra Yantra at Delhi also has a Samrat construction built in it, with a separate instrument, the Niyat Chakra, separating the morning and afternoon halves of the Samrat.The quadrant arcs, placed perpendicular to the inclined wall of the instrument, are in the plane of the equator.

Figure 1. The Laghu (small) Samrat Yantra of the Jantar Mantar observatory, Jaipur. The inset shows the plaque for the instrument displayed at the observatory. The texts for all such plaques at the Jaipur observatory, have been provided by the author. The Samrat Yantra consists of a triangular wall to act as the gnomon, with semicircular arch placed perpendicular to the inclined wall on which the shadow of the gnomon moves parallel to the equator, thereby moving equal distances in equal hours. (Image credit: Nehru Planetarium, New Delhi)

With such a configuration, on the quadrant arc, the shadow of the triangular wall moves equal distances in equal intervals of time. It is this movement that is used to tell time. When the shadow of the triangular gnomon falls on the upper end of western quadrant, it is 6:00 AM sundial time. At solar noon, the shadow disappears from the western quadrant and reappears on the eastern quadrant. At 6:00 PM sundial time, the shadow hits the topmost point of the scale marked on the eastern quadrant. The times intermediate to these can be marked off as equal segments with the least count of time measurement, determined by the size of the quadrant arcs. The Brihat Samrat Yantra and the Samrat Yantra at Delhi had 2 seconds as their original least count, and the smaller instruments had a least count of 20 seconds. These times have to be corrected, to obtain the clock time.

The correction factor which has to be applied to the observed solar time, is displayed for the day near the Laghu Samrat Yantra at Jaipur observatory (*Figure* 1). This correction factor includes the varying equation of time arising from the ellipticity of Earth's orbit around the Sun, and the tilt of the axis of rotation of the Earth with respect to the orbital plane, as well as the constant correction arising from the fact that the sundial gives time according to the local meridian, while civil time uses one longitude for the entire extent of validity of Indian Standard Time.

Time measurements have been taken with the Samrat Yantra instruments of all the Jantar Mantar observatories by the planetarium team. The Jaipur, Varanasi, and Ujjain instruments have the markings for time measurement on their surfaces, which has been used for the collected time measurements shown in various figures here.

In all these time measurements and calculation of errors, the reference clock time was set to 1 second accuracy at the National Physical Laboratory, New Delhi. The digital display clock being used for our observations was seen to be in error by 2 seconds, in about 24 hours. The clock initially set at NPL would be reset through telephonic time signals, every day of observations undertaken outside Delhi.

Figure 2. A view from west of the Nadivalaya Yantra at Jaipur. The inclined dial plate on the right side is the south plate and the one on the left, whose edge can just be discerned, is the north facing plate. (Image credit: http://mountainsoftravel-photos.com/)

The Nadivalaya

This is a version of an equinoctial sundial, which is different from the design of the Samrat Yantra (*Figure* 2). The two circular plates that are facing the north and the south are inclined towards the south at such an angle that they are parallel to the plane of the equator of the Earth. At the centre of the circular dials are rods that are projecting perpendicularly outwards. These rods are then, parallel to the axis of rotation of the Earth. The movement of the shadow of these rods, on the circular dial, indicates the time (*Figure* 3).

From the autumn equinox to the spring equinox, the dial plate facing south will be sunlit and is to be used for telling the time. From the spring equinox to the autumn equinox, the dial plate facing north is sunlit and is to be used for telling the time.

In our observations, an extrapolation of the shadow line all the way to the scale was achieved through image processing (*Figures* 4 and 5). While photographing the shadow, care was taken to image from a perpendicular direction to the plate, to avoid parallax errors in reading the shadow. The calibrated clock, placed visibly in this image, allows one to obtain the clock time corresponding to the instance of measurement of the sundial time, accurately.

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The Delhi Samrat Yantra does not have any markings on the surface. Moreover, one half of the instrument – the lower portion, where the quadrant arc touches the triangular wall, has been filled up with cement at some time, by the Archaeological Survey of India, presumably, to tackle water seepage problems which seems

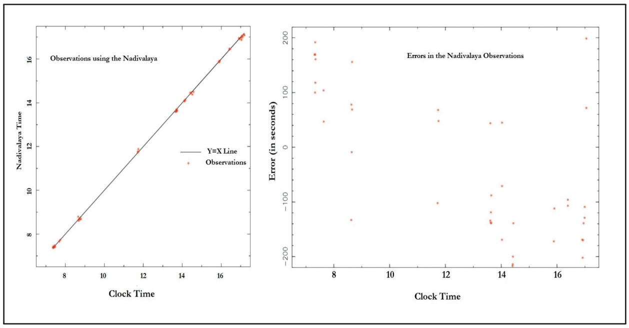

Figure 3. Time measurements and errors, using the low precision Nadivalaya of the Jaipur Jantar Mantar observatory.

Figure 4. Shadow of the gnomon on the north facing wall of the Nadivalaya. The actual shadow is small and has been extended virtually in the image. The clock placed visibly allows observations of both the calibrated clock time and the sundial time to be taken through one image.

to have beset the instrument in the past. On account of this, one half of the instrument is considered to be in an unusable state and thus, time measurement with this instrument has not to been possible [2].

Calibration Observations with the Delhi Samrat Yantra

Participants in the calibration observations with the Samrat Yantra at Delhi : Anurag Garg, Dayal Singh, R K Chikara, K S Balachander, Sneh Kesari, Pritpal Kaur and Vikrant Narang.

Time observations with the Delhi Samrat Yantra were attempted in 2006, using the instrument in its current state (*Figure* 6).

Near the central gnomon of the Delhi Samrat Yantra, a horizontal cemented platform is present that seems to be a continuation of the quadrant. This platform seems to indicate that the renovation work that resulted in the destruction of segments of the quadrant, envisaged a mixed usage of the Samrat Yantra. The instrument can be used as an equinoctial sundial, using the original

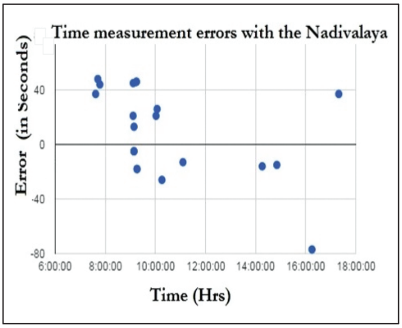

Figure 5. Errors in time measurement taken with a small Nadivalaya at the Jantar Mantar observatory on the Manmandir terrace, Varanasi.

calibration of Jai Singh's astronomers on the intact segments of the Samrat Yantra, and a calibration analogous to a European sundial on the horizontal platform where the quadrants are missing. In its current state, if the markings on the instrument are redone, the Samrat Yantra will be a unique sundial in the whole world. It will be an equinoctial sundial with an oriental design for its quadrants, for the morning and evening hours, and more like a European sundial, close to noon hours.

From September–December 2006, temporary markings for time observations were prepared for every minute of time from 6:00 AM to 6:00 PM sundial time, with such a mixed marking scheme. This marking scheme, however, was derived from observations, rather than through a theoretical demarcation of its geometry between the two different designs, now mixed up in the instrument. On account of the many masonry irregularities that were then present on the instrument, it was very difficult to get accurate measures of the overall lengths involved in the various sections of the quadrant, and thus an observational calibration was attempted at that time.

The shadow position was marked for every minute of sundial time, by applying the appropriate longitude correction, and the equation of time correction to IST. The clock used to make this calibration was repeatedly set to 1 second accuracy with kind help from the Timing and Frequency Division of NPL.

The prepared calibration markings were tested through public observations on the winter solstice 2006. About 450 time measure-

Figure 6. Initial calibration attempts on the horizontal platform made over the concrete filling in the interior of the Delhi Samrat Yantra in 2005. This initial calibration was undertaken simultaneously with outreach activities. Later, a more accurate observational calibration of markings for every minute, were made during the winter of 2006, on this instrument.

ments were taken by the visiting public and invited school students. These observations (*Figure* 7) show that the instrument is intrinsically capable of measuring time accurate to a second! There is a caveat, however, to this demonstration. What was attempted, was an observational calibration, which was used later to read the time from the instrument. This process would have washed out any intrinsic vagaries of the instrument. Such intrinsic vagaries is bound to have crept into all the masonry constructions of such gigantic scale, arising from any small deviations from the intended alignments and placing of the instrument surfaces and markings.

The Delhi instrument needs the surface markings to be restored, before visitors could appreciate the achievable accuracies. The Jaipur instrument has the surface markings inlaid on marble (a result of 20th century renovation), which is not good from the point of view of observations. The translucency of marble hinders accurate shadow reading. It would not be a good practice to restore the surfaces of any of the larger instruments at the Jantar Mantar observatories with marble. The smaller instruments like the Laghu Samrat Yantra are not handicapped to the same extent by the presence of marble, as the distances from the gnomon are shorter, and the resultant fuzziness of the shadow is much less.

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Jantar Mantar Instruments for Local Co-ordinate Measurements.

Participants in outreach observations with these instruments at Delhi and Jaipur : All Planetarium staff, Sneh Kesari, C B De-

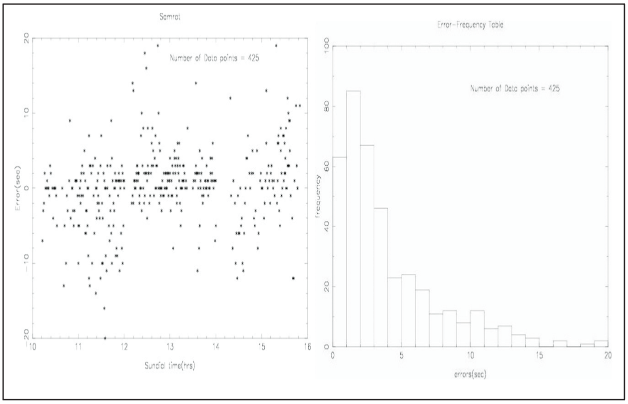

Figure 7. Time observations with the temporary markings made on the Samrat Yantra quadrant and floor. Markings were made for every minute and public observations were conducted on winter solstice day 2006. The figure on the left shows the time measurement errors, and the one on the right shows the error frequency distribution.

vgun, Vikrant Narang, Vidur Prakash, Megha Rajoria, Priyanka Sharma, SPACE, ITIHAAS.

The instruments which make local (horizon) co-ordinate measurements in the Jantar Mantar observatories are the Unnatamsa Yantra of the Jaipur observatory which measures altitudes of celestial objects, the Digamsa Yantra of Jaipur, Ujjain, and Varanasi observatories, which measures azimuths of celestial objects, and the Ram Yantra of Delhi and Jaipur observatories, which can measure both altitude and azimuth.

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Ram Yantra is a cylindrical instrument built in such a way that one can easily determine the altitude and azimuth of the Sun (or other celestial objects) in the sky.

In the absence of markings on the Delhi instrument, the following procedure has been used for all outreach measurements with this instrument.

Another length to be measured is the distance of the shadow edge from the central pillar. Tan^{-1} (Gnomon length/Distance to the shadow) then gives the altitude.

The instrument has consistently shown accuracies of about 0.1 degrees, even with the most cursory of observations [7]. Restoration of the Delhi Ram Yantra instrument, removal of any surface level irregularities on the instrument, as well as attempts to increase the accuracy of shadow reading should certainly improve this accuracy substantially.

Hemispherical Bowl Instruments – the Sky in a Bowl

Participants in outreach observations with these instruments at Delhi and Jaipur : Ramesh Chikara, Naresh Kumar, Shyam Kumar, Pulkit Agarwal, Pritpal Sandhu, Lavanya Nemani, Sonia Munjal, C B Devgun, Vidushi Bhatia, Sneh Kesari, Anees Siddiqui, SPACE, Siddharth Madan, Priyanka Gupta.

Jai Prakas (*Figure* 8) are twin hemispherical bowl instruments, each a reflection of the sky above and marked in sectors, and gap regions. The center of the bowl is a reflection of the zenith. Starting from the center, lines are marked along the bowl to indicate the azimuth. Altitude circles are marked along the length of the bowl. Reflection of a cross wire stretched north-south and east-west over the surface of the bowl, shows the position of the Sun in the sky.

The bowls are complementary, in the sense that the gap region in one bowl is the sector region in the other and *vice versa*. The idea being that the observer needs to be inside the bowl, to take readings – which means that readings would not be possible in the regions where the observer would be able to walk – and hence the complimentary bowl.

At the surface level on the depressed bowl, there are pegs in the north-south and east-west direction to hold cross wires. One has to view the shadow of the junction of the cross wires on the bowl of the instrument to determine the co-ordinates of the Sun in the daytime sky. Night time observations presumably use the gap

Figure 8. A view of the bowl shaped Jaiprakas instruments looking southwards from the stairs of the Samrat Yantra gnomon. The cylindrical Ram Yantra instruments can be seen in the background.

regions with the eye set level with the spherical surface of the instrument, looking at the celestial object through the cross wire.

The sectors on the surface of the hemisphere can be marked with altitude and azimuth circles, diurnal circles, lines for the right ascension, the declination circles, and also circles showing rise and culmination of the zodiacal constellations.

Conclusion

The major aspect about these observatories, is their inspiring presence in public space, allowing a very hands on experience of astronomy for anyone visiting the observatories. Notwithstanding their current state of disrepair in some cases, the Jantar Mantar instruments are yet in a good condition as far as observations by senior school and college students are concerned, and this particular aspect of outreach activities – the usage of the Jantar Mantar as a teaching laboratory of astronomy, should be continued.

Box 1. Call for Sundial Observations

This is a call for sundial and other positional astronomy observations with simple instruments that can be undertaken by anyone from anywhere in India. These observations, if undertaken with care towards accuracies achievable, will make a database of positional astronomy observations using instrumentation in the spirit of the Jantar Mantar observatories. These observations will allow us to better appreciate the practical accuracies achievable with varying sizes of such instruments.

Details of possible activities in this direction, of construction of simple instruments and information on submitting the results obtained is available at: `http://astron-soc.in/outreach/` and the Facebook page 'ASI Poec' of the Public Outreach Committee, Astronomical Society of India, which is giving this nationwide call for sundial observations.

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