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Sundial for Time–keeping in Jaisalmer Fort

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Abstract

The paper reports the study of a special Sundial installed in the Jaisalmer fort in 1861 CE. It reveals that the graduation is based on the traditional Indian system of time-keeping. The divisions represent equal time intervals of 24 minutes corresponding to one *ghaṭi*. An attempt has been made to estimate the accuracy of the dial readings through our own observations.

Key words: Accuracy of Sundial, Indian system of time keeping, Sundials.

1. Introduction

Time-keeping has been very significant in the scientific as well as socio-cultural traditions around the world. There is no human invention more ancient or more interesting, than that of Sundial; so ancient that the exquisite essayist, Charles Lamb says,

> "Adam could scarce have missed it in Paradise; and so interesting, that we may be sure that man's first want, after supplying craving of hunger, would be to invent some instrument by which he could measure the day-time into proportions (Alfred Gatty, 1872)."

In the significant contributions such as Alfred Gatty in her book *Sundials* has elaborated this fact at length.

Stone observatories have played an important role in the development and evolution of Astronomy (Sharma, 1991, 2008, Shylaja, 2011). Prahlad Singh in his book, Indian and Islamic Stone Observatories (Singh, 2009) and Kochar and Narlikar (1993; 1994) have documented the heritage of stone observatories and variety of time-keeping instruments in a comprehensive manner. And yet, there are a few historical intellectual contributions that have not caught the eyes of the scholarly world.

Herodotus (443 BCE) said, "It was from the Babylonians that the Greeks learned concerning the pole, the gnomon, and the twelve parts of the day (Kaye, 1973)." Since the ancient Greek experimentations, around the world, it has been a tradition of dividing a day into twelve parts. But, in ancient India it was not strictly so. In one of the ancient Indian traditions, the day is divided into 30 parts as well (Bose, 1971). The Sundial in Jaisalmer fort is based on one of these Indian traditions. The Sundial is located on the roof top of the Raj Mahal Palace Museum in the Jaisalmer fort founded by Rajput ruler Rawal Jaisal in the year 1156 CE (Tod, 1828).

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2. The Sundial in Jaisalmer Fort

The Sundial is carved on a yellow lime-stone slab which is abundant in Jaisalmer. The dial is mounted on a platform in the South-West corner of the roof top of Raj Mahal palace museum in the Jaisalmer fort (Fig. 1).

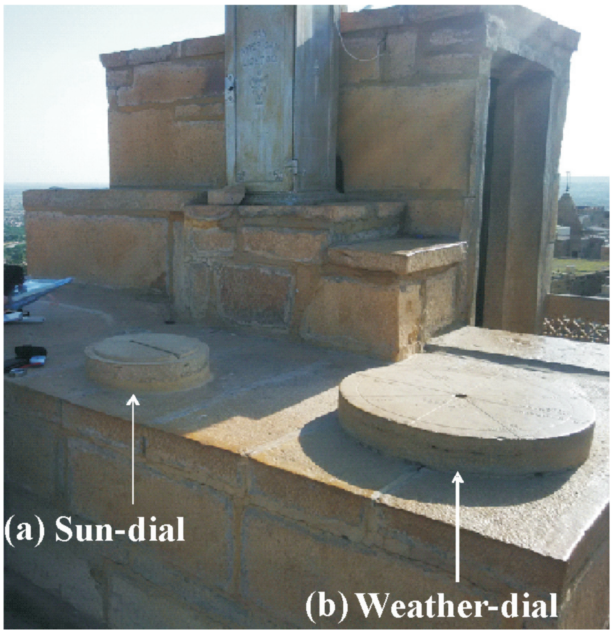

Fig. 1: (a) Sundial in Jaisalmer fort with a straight groove for attaching a triangular gnomon; and (b) Weather-dial with a hole at the centre for a flag post.

The inscription on the Sundial (Fig. 2) is in Devnagari script as follows:

महाराजाधिराज राज राजेसर महारवलजी श्रीश्री १०८ श्री राणजीत सिंह जी बहादुर जंतर लगा करायो हसंते गजधर सरूपजी खमाणी सं. १९१६ २ मिती मागसरस ६१

An appropriate English translation of this could be given as:

> At the behest of Maharjadhiraj Raj Rajeshwar Maharawalji Shree Shree 108 Shree Ranjit Singhji Bahadur, this instrument was installed by Gajdhar Saroopji Khemani on 2nd day of the Margshirsh month of Samvat 1916, 1861 CE.

Thus, according to the inscription on it (Fig. 2), the Sundial was created on 2nd day of the second half of *Mārgśirṣa* Month of *Samvat* 1916 that upon conversion implies 26th November, 1861 CE, and that it was created under the instructions of the ruler Mr. Ranjeet Singh (1846-1864 CE). There used to be an observer around the dial who after regular interval used to ring a giant bell, apprised Dr. Raghuveer Singh the Superintendent of the Raj Mahal Palace Museum.

Fig. 2: Close up view of the Sundial.

The erstwhile princely state Jaisalmer is known to have a separate calendar Bhattik *Samvat*, which is well mapped with the *Vikram Samvat* except for the fact that the first month of *Bhattik Samvat* is *Mārgśirṣa* and not *Caitra* (Rajasthan District Gazetteers- Jaisalmer, 1973; and Dasharath Sharma, 1966). However, *Vikram Samvat* and the Gregorian calendar were in fashion in the medieval period also, but, *Mārgśirṣa* month was still considered for the new-year celebrations and other auspicious occasions. Thus, the inscribed day of the *Mārgśirṣa* month corresponds to 26th November, 1861 CE.

The Sundial was used for some time and later it was dumped in the store of the palace. It was rediscovered in 1993 CE by Dr. Raghuveer Singh (Raj Mahal palace Museum, Jaisalmer) when he took over as the Superintendent of the palace and he got it reinstalled on the roof top of the palace. Close to the Sundial, there is another interesting instrument called Weather-dial (Fig. 1 (b)) which is discussed later in the section-4 of the present paper.

3. Observation and Analysis

In order to check the functioning of the Sundial, we installed a makeshift triangular gnomon N - 27° direction exactly fitting the groove on the dial as shown in Fig. 3. The time derived by observing the shadow of the gnomon on the horizontal dial matched fairly well with Indian Standard Time (IST) with all necessary calibrations due to longitude difference and the equation of time for the date. The physical measurements are as follows:

The position of Sundial as per GPS readings:

N - 26° 54′ 46.14″; E - 70° 54′ 48.36″; and altitude: 253.4 meters.

Diameter of the Sundial: 36.5 cm.

This is based on system of time-keeping in Indian calendar (Bose, *et al.* 1971). This could be understood as follows:

24 minutes = 1 *ghaṭi*

$2\frac{1}{2}$ *ghaṭi* = 1hour;

30 *ghaṭi* is = 12 hours; and 12 hours = 4 *praharas*.

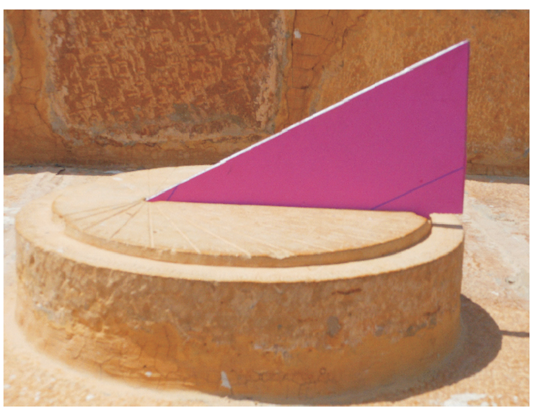

Fig. 3: Sundial with a makeshift triangular gnomon with inclination N - 27° . (Angle ~ N - 27° is the latitude of Jaisalmer)

We observed that the makeshift gnomon did not cast any shadow on the dial at the time of meridian that is local noon on 13th September, 2015 as depicted in Fig. 4 (a). Moreover, we recorded observations and further investigated on 9th May, and 25th and 26th June, 2016. Observations on June 25th and 26th are important as they were close to 21st June the summer solstice.

There is difference of 11.58° between the longitudes of Jaisalmer and IST (82.58°). The local time of Jaisalmer differs from IST by 11.58x4=46.34 minutes. Further, there ought to be correction of 3.6 minutes on 9th May, and -2.4 minutes on 25th and 26th June as per the equation of time. The local noon was observed on 9th May at ~ 12:49 *Hr* IST, and on 25th and 26th June at ~ 12:44 *Hr* IST on 13th September, 2015.

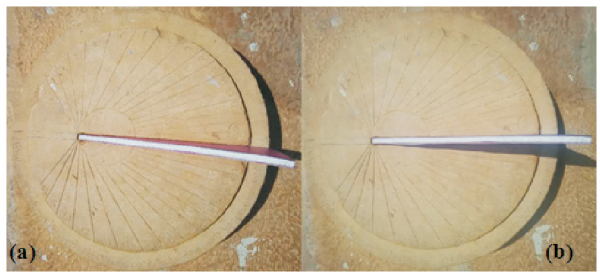

Fig. 4: The Observations on the Sundial on 13th September, 2015 with makeshift triangular gnomon: (a) At local noon with no shadow; and (b) ~48 minutes (2 *ghaṭis*) post meridian.

As the Sun rises from the North of equator, we observe shadow (Fig. 5 a) of the gnomon even before the East-West line as expected.

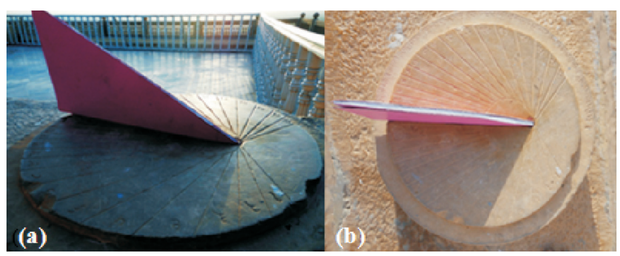

Fig. 5: (a) Observation at Sun rise on 9th May, 2016 (6:28 AM): The shadow is below the East-West line; and (b) Observation just after the Sun rise on 9th May, 2016 (7:28 AM).

We recorded observations on the Sundial on 9th May, 25th and 26th June, 2016. The observations are as follows:

Table 1: Observations on 25[t]h and 26[th] June, 2016.

		Time (IST)		
S. No.	**Graduation**	**9[th] May, 2016**	**25[th] June, 2016**	**26[th] June, 2016**
1	**1**	**Sun Rise: 06:02 AM** (Not recordable)	**Not recorded**	**Sun Rise: 05:54 AM** (Not recordable)
2	**2**	Not recordable	Not recorded	Not recordable
3	**3**	06:16 AM		06:22 AM
4	**4**	06:40 AM		06:46 AM
5	**5**	07:04 AM		07:10 AM
6	**6**	07:28 AM		07:34 AM
7	**7**	07:52 AM		07:58 AM
8	**8**	08:16 AM		08:22 AM
9	**9**	08:40 AM		08:46 AM
10	**10**	09:04 AM		09:10 AM
11	**11**	09:28 AM		09:34 AM
12	**12**	09:52 AM		09:58 AM
13	**13**	10:16 AM		10:22 AM
14	**14**	10:40 AM		10:46 AM
15	**15**	Not recordable	Not recordable	Not recordable
16	**16**	Not recorded	Not recorded	Not recorded
17	**17**	Not recorded	Not recorded	Not recorded
18	**18**	12:16 PM	*12:22 PM	12:22 PM
19	**Zenith**	12:40 PM	12:44 PM	12:44 PM
20	**Zenith**	12: 50 PM	12:52 PM	12:52 PM
21	**1**	12:58 P M	01:08 PM	01:08 PM
22	**2**		01:32 PM	

Table 2: Observations on 9[th] May and 26[th] June, 2016 and their respective Shadow Angles

Graduation	**Observed Shadow Angle** *h* (From the North-South Line)	**Time (IST)**	
		9th May, 2016	26th June, 2016
Zenith	0^{O}	12:40 PM	12:44 PM
18	3^{O}	12:16 PM	12:22 PM

* The observations on 25[th] June were recorded only after 12:22 PM. Observations on 9[th] May and 26[th] June could be tabled with respect to Hour angle H= 0^{O} as:

17	6^{O}	Not recorded	Not recorded
16	9^{O}	Not recorded	Not recorded
15	Missing Graduation	Not recordable	Not recordable
14	13.5^{O}	10:40 AM	10:46 AM
13	18^{O}	10:16 AM	10:22 AM
12	22^{O}	09:52 AM	09:58 AM
11	28^{O}	09:28 AM	09:34 AM
10	33.5^{O}	09:04 AM	09:10 AM
9	39.5^{O}	08:40 AM	08:46 AM
8	47^{O}	08:16 AM	08:22 AM
7	56^{O}	07:52 AM	07:58 AM
6	66.5^{O}	07:28 AM	07:34 AM
5	77.5^{O}	07:04 AM	07:10 AM
4	90^{O}	06:40 AM	06:46 AM
3	102.50^{O}	06:16 AM	06:22 AM
2	113.50^{O}	Not recordable	Not recordable
1	$12.4.00^{O}$	Sun Rise 06:02 AM (Not recordable)	Sun Rise 05:54 AM (Not recordable)

It is noticeable that the time difference between consecutive readings is 24 minutes. To cross-check that this is exactly the intended design, we compared the angles for every 24 minutes from Noon with calculated values using the formula. We now calculate the theoretical values of shadow angle using the formula:

$$\tan h = \sin(\Phi) * \tan [H].$$

(1) Where, h is the shadow angle, $\Phi = 27^{O}$ (latitude angle) and H is the hour angle.

We now estimate the error between the observed and theoretical value of shadow angles h and h' with time and plot their variation with time.

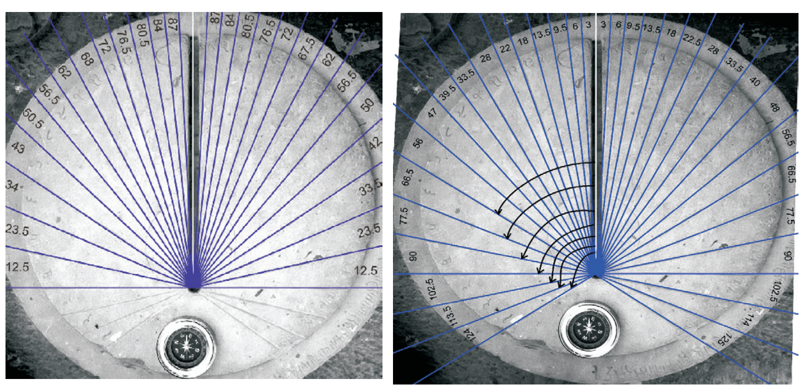

Fig. 6: The shadow angles: (a) As measured about the East-West line from the foot of the gnomon; (b) Measured from the meridian line.

Fig. 6 (a) and 6 (b) represent the scheme of angular division or graduations drawn on the Sundial. Computer graphics were used to simulate the lines superimposed on a photograph of the dial taken carefully from a point just vertically above the center of the dial.

We now summarize all our observations measured in time and corresponding shadow angles and estimate the error between the observed shadow angles and their theoretical values.

Table 3: Variation in Observed and Theoretical Values of Shadow Angles h and h' with Time

Graduation	IST (26th June)	Time Interval (From Zenith)	Shadow Angle From the North-South Line (At the foot of the gnomon)		Error
		Δt (Minutes)	Observed value h	Theoretical Value h'	$(h-h')$
19	12:44 PM	0	0^{O}	0^{O}	0.0^{O}
18	12:22 PM	24	3^{O}	2.72^{O}	0.28^{O}
17	Not recorded	Not recorded	6^{O}	5.49^{O}	0.51^{O}
16	Not recorded	Not Recorded	9.5^{O}	8.36^{O}	1.14^{O}
15	Not record-able	Not recorded	Missing Graduation	11.39^{O}	-
14	10:46 AM	120	13.5^{O}	14.64^{O}	-1.14^{O}
13	10:22 AM	144	18^{O}	18.20^{O}	-0.20^{O}
12	09:58 AM	168	22^{O}	22.17^{O}	$-.17^{O}$
11	09:34 AM	192	28^{O}	26.69^{O}	1.31^{O}
10	09:10 AM	216	33.5^{O}	31.92^{O}	1.58^{O}
9	08:46 AM	240	39.5^{O}	38.09^{O}	1.41^{O}
8	08:22 AM	264	47^{O}	45.47^{O}	1.53^{O}
7	07:58 AM	288	56^{O}	54.33^{O}	1.67^{O}
6	07:34 AM	312	66.5^{O}	64.84^{O}	1.66^{O}
5	07:10 AM	336	77.5^{O}	76.92^{O}	$.58^{O}$
4	06:46 AM	360	90^{O}	90^{O}	0.0^{O}
3*	06:22 AM	384	102.50^{O}	103.07^{O}	-0.57^{O}
2*	05:58 AM**	408	113.50^{O}	115.09^{O}	-1.59^{O}
1*	05:34 AM**	432	124.00^{O}	125.61^{O}	-1.61^{O}

*Graduations 1, 2 and 3 are below the East-West line.

**These observations (time and images) were not recorded.

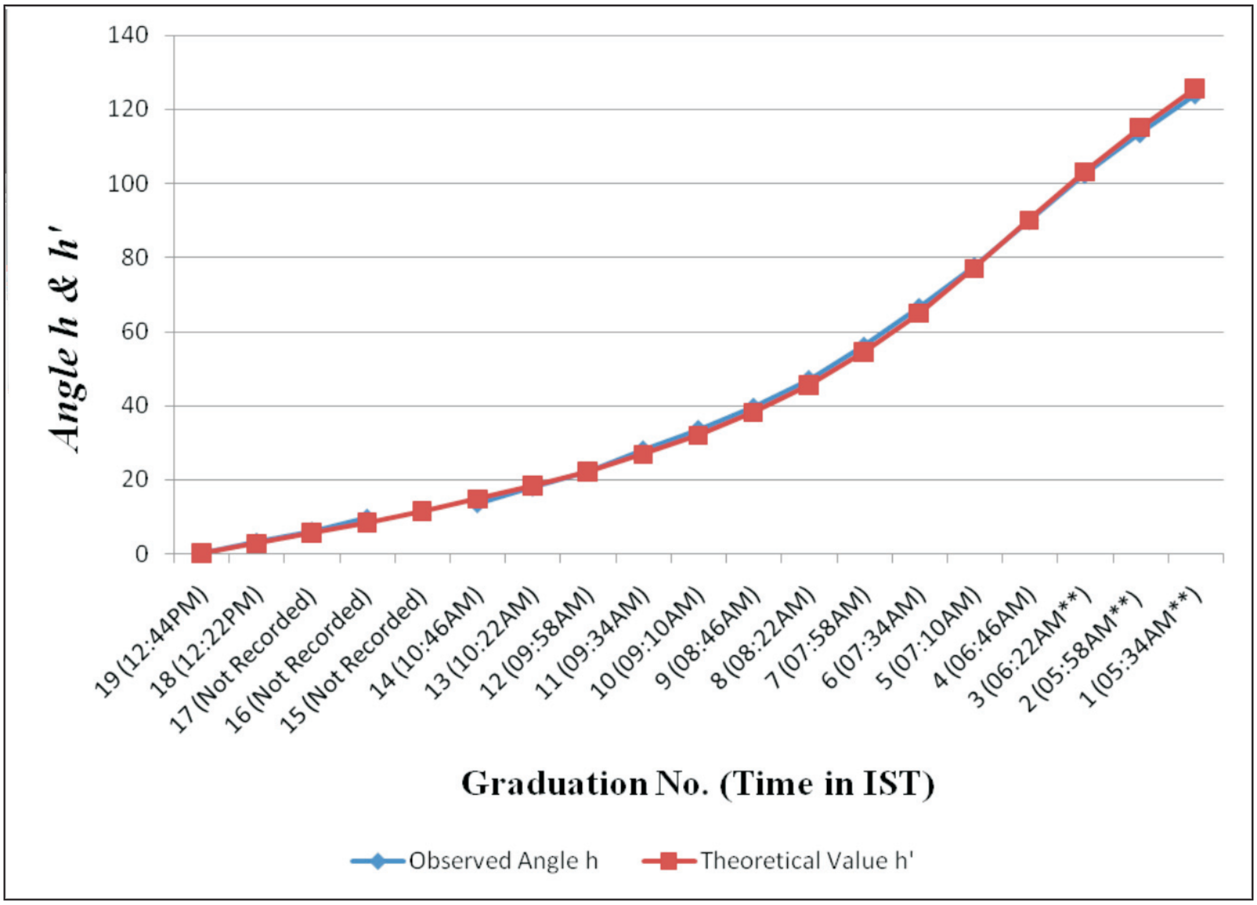

Fig. 7: Curve representing the error between the observed and theoretical value of shadow angle h and h' with time.

We notice that there is reasonable overlap of the two curves representing shadow angles h and h'. The total time interval recorded for passage of the shadow across 16 graduations is 384 minutes. This proves the point that the graduations were intended for a time difference of 24 minutes as per the Hindu time reckoning system.

Observations as well as theoretical calculations reveal that one graduation corresponding to shadow angle 78.70^{O} from the East-West line that is 11.30^{O} from the meridian line is missing on the dial. This is found on both the sides of North-South line.

4. Weather Dial

The weather dial in Jaisalmer fort is an interesting instrument (see Fig. 8). To understand the functioning of the weather dial, we need an extensive scientific study based on observations for several years. However, the basic information known about the weather dial indicates that it works on the wind-pattern and the direction of the wind plays an important role in the rainfall.

A flag post used to be mounted at the central hole of the dial to indicate the wind direction. It is said that observations of the wind directions were recorded on Akhātīj (*Akṣaya Tritīyā*), a particular day in Indian calendar which generally occurs in late April or May. And wind pattern in turn can tell us about the possible rainfall.

In Jaisalmer region cold winds blow from West to East in the winters. Based on experience, there is belief that the wind pattern in Jaisalmer changes around *Akhātīj* (*Akṣaya Tritīya*). This seems to be in reasonable agreement with modern weather science (Forecasting manual, IMD; Das, *et. al*, 2002). In winters winds blow from northwestern high pressure zone to the low air pressure zones. This pattern changes around early summer. With the apparent northward movement of the Sun towards the Tropic of Cancer in late March, temperature rises in North India. April, May and June are the months of summer in North India. The differential heating of land and sea is believed to be the primary cause of the monsoon by meteorologists. Low pressure at Inter Tropical Convergence Zone (ITCZ) which is located over North India in month of May becomes so intense that it pulls the trade winds of the southern hemisphere northwards. The wind pattern thus turns south-westerly in western Rajasthan in early May (Forecasting Manual, IMD. 1972; Das, *et. al*, 2002). This is prominent cause of the monsoon.

A similar tradition of rainfall forecasting is observed in Jantar-Mantar observatory at Jaipur also (Singh, 2009; *Ibid* 58-60). This is a tradition continued for about three hundred years since the times of Maharaja Jai Singh. In Jaipur observatory the observations for rainfall are made on the day of '*Guru Pūrṇima'* that is full moon day of *Aṣādha* month of Indian calendar which occurs on some day in July.

Since, weather forecasting is based on statistical analysis, these observations should continue throughout the season. Thus, in some sense, observations on *Akṣaya Tritiyā* could be meant for early or advance forecasting of monsoon. And as the weather forecasting is dependent on repetitive observations and statistical analysis, an extensive scientific study based on observations for couple of years is suggested.

Fig. 8: Weather-dial with a central hole at the centre for a flag post.

5. Discussion

It is interesting to note that different geographical regions and different cultures have different means and methods of time-keeping. The Sun-dial in the Jaisalmer fort was a functional time-keeping instrument with a fair degree of accuracy.

It is interesting to note that the dial was designed to read intervals of 24 minutes as needed by the local calendar makers. The dial is usable even today by placing a gnomon. However, there are errors, as mentioned in the table which are because (i) the dial was not installed properly aligning its axis in the N-S direction; and (ii) The location is not suited for afternoon and evening observations. If it is relocated to a better location with exact N-S alignment, it will become an 'active' Sundial reading *ghaṭis*. The extra lines to the South of E-W line may not be of relevance now; but its use for any other purpose needs to be explored.

However, the Sundial while it was reinstalled was not exactly placed in the North-South direction. There is an error of about 4^{O} with the North-South direction as shown in the Fig. 9. The compass used for the measurement is accurate up to one degree. And the observed time from the dial was still in fair agreement with our watches within a minute.

The grove along the meridian line is about 1cm wide. The graduations on the dial all converge at the intersection of meridian line and the East-West line. It was difficult to make *in situ* measurements of the angular separation of the graduations with common tools. So, we used computer graphics to simulate the lines superimposed on a photograph of the dial taken carefully from a point just vertically above the center of the dial. The workmanship on the dial though, appears a bit crude, it is none the less a functional one.

Also, we worked out the theoretical calculations for the angular divisions graduated in time by 24 minutes, and notice that there is deviation of $.5^{O}$ - 1.84^{O} between the theoretical and the observed values.

Theoretical calculations reveal that one graduation corresponding to shadow angle 78.70^{O} from the East-West line that is 11.30^{O} from the meridian line is missing on the dial. This discrepancy is found on both the sides of North-South line.

Fig. 9: Sundial recorded with a GPS application of a smart phone.

There is no structure or marking implying the positioning of the dial. With time, the lime-stone slab bearing the Sundial in Jaisalmer fort is getting deteriorated mainly due to weathering effects. These relics of the past need better upkeep and maintenance.

Acknowledgment

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