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Direct Tracking Error Estimation on a 1-Axis Solar Tracker

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Abstract

The characterization of the precision of a solar tracker used in solar thermal collectors is not currently standardized. Nowadays, existing testing standards consider a solar tracker as part of the solar collector and do not take into account the tracking precision, without any kind of tracking characterization or checking. This paper is focused on the estimation of tracking errors using a direct procedure to estimate the maximum tracking angular deviations of a solar tracker. First, a testing procedure of a solar tracker has been defined. Secondly, the real tracking error of a low-cost 2-axis solar tracker has been measured with a simple method using a digital inclinometer. The direct characterization of the elevation of a solar tracker in one axis has been compared to the solar elevation, in order to estimate the angular deviation of the tracker in one angle. Finally, the statistical distribution of the tracking error has been calculated and compared to the acceptance angle of medium temperature concentrators to check if its precision is enough for its optics. The measurement repeatability was checked of ± 0.05°. The maximum instantaneous error of elevation for this tracker was more than 3º but in general was within ±2º. The accuracy of the tracking considering no positioning error was within ±0.6º. The acceptance angle of different solar concentrators has been compared to the solar tracking accuracy. It has been conclude that the medium temperature collectors studied were adequate with this solar tracker.

Keywords: One-axis tracking; elevation characterization; testing procedure

1. Introduction

There are different methods to characterize the solar tracker elevation. To check the aligning of solar tracker and control it, some sensor produces an electronic output signals. The first sensor of this type was introduced by Greene and Tan (1988). This system was composed of several photodiodes and CCD device which managed to quantify the movement of the image in two axes. Huang and Sun (1996) showed a solar sensor device consisting of two photovoltaic cells separated by a shade wall between them. If it causes a mismatch, then the shadow cast on a PV cell results in a reset command guidance system. Oliveira (2008) presented a device composed of a phototransistor coupled to a shading structure. Davis et al. (2009) filed a marketable device. This instrument was a high-resolution sensor using images processing treatment. Minor and Garcia (2010) presented a solar tracking system based on a WebCam using an image processing. This device was able to measure the tracking with an accuracy of 0.1°.

This paper analyzes whether a low cost solar tracker in 2-axis is precise enough for some medium temperature solar thermal concentrators. In this experimental study, a direct measurement of a solar tracker is

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performed using a digital level to measure their inclinations. Then, this measurement is compared to the solar elevation. Finally, the average and probability distribution of tracking errors have been calculated.

2. Materials

2.1. Solar tracker and digital level

The solar tracker, tested in this study, is a brand name Feina model SF09 (See Figs. 1 for a general view of the solar tracker and Fig. 2 for a view of the motor gauges).

Figure 1: Picture of the whole solar tracker for collector testing.

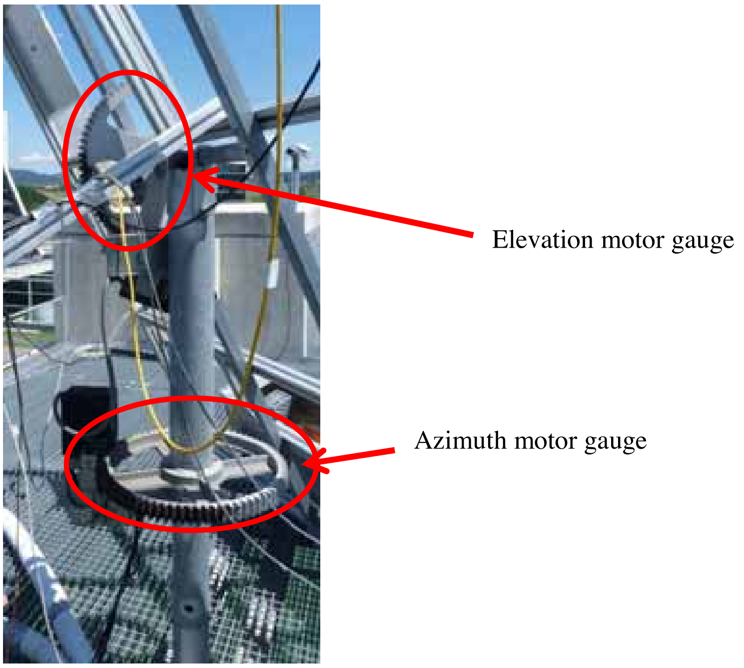


Figure 2: motors of solar tracker (a) Motors (b) electronic control

This solar tracker is a 2-axis tracker with low precision used for photovoltaic plants with no concentration. It is a cheap (~1000€) solar tracker in the Spanish market (for more information about the solar tracker visit www.feina.es). In CENER, it had been adapted for solar thermal collectors testing for which a precision of ±2° is required. A metallic structure had been added on the tracker for the solar collector mounting and the testing sensor collocation (See Fig. 1).

The equipment used to measure the tilt of the solar tracker was a digital inclinometer brand name Mitutoyo model PRO 3600 with connection RS-232C for communication (See Fig. 3).

Figure 3: Picture of the Digital Protractor

According to manufacturer characteristics, the resolution is of ±0.01° (from 0° to 9.99°) and of ±0.1° (from 10° to 90°). The accuracy is ±0.05° (from 0° to 10°), ±0.1° (from 80° to 90°) and ±0.2° (from 10° to 80°). Using the connection RS-232C, the resolution is of ±0.01° from 0 to 90º.

The repeatability of the measurement was checked on a fixed stable table in order to estimate the precision of the measurement. An offset in the measurements was observed of 0.15º during a period of 30 min. The repeatability was checked of ± 0.05° (See Fig 4) and the standard deviation was smaller than 0.015º.

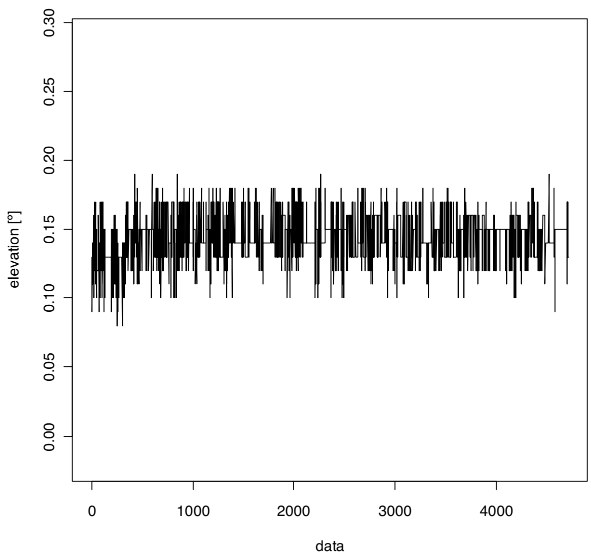


Figure 4: Measurement of the inclinometer on the fixed table

2.2. Solar concentrators

The solar concentrators studied in this paper were selected from a review of the main parabolic through collector (PTC) (Fernandez-García et al 2010) in order to match solar tracker precision up to ±2º. Three parabolic through collectors (PTC) with a linear receiver tube placed on the focal line of the reflector parabola were selected. The dimensions have been summarized in Table 1. Those concentrators are linear, the receiver tube is located on a focal line, so they would only need a single-axis tracker, but the study compares them with the tracker available.

Tab. 1: Dimensions and properties of solar concentrators

Compagny	**Solitem**	**Solar Kinetics Inc**	**IST**
Model	PPTC 1800	T-700	PT1
Aperture area (m^2)	9.162	77.96	14.03
Aperture width (m)	1.8	2.13	2.3
Length (m)	5.09	36.6	6.1
Acceptance angle (º)	2.09	2.22	2.41
Geometric concentration ratio	15.08	16.42	14.36

3. Methodology

3.1. Tracker elevation accuracy estimation

The digital level was located on one arm of a solar tracker by a plastic flanges in order to fix the perpendicular level to the horizontal axis (See Fig. 3).

Figure 3: Location of the Digital Protractor

A connection to a PC was done by a 20 meters cable RS, the digital level output is recorded every 0.5 seconds and the average data are calculated every 5 seconds.

In each test the solar tracker was configured introducing the timeset with a precision of one second and the solar elevation and azimuth angles were theoretically calculated. Then, the motors were moved by a manual mode until the solar tracker was ~~is~~ oriented to the correct positions. A shade stick with a ±1° precision was used, in order to leave the solar tracker, for the initial position, at the normal of the sun direction. This stick projects a shadow on the white screen if the solar radiation is not perfectly perpendicular to the solar tracker, and some circles indicate the angular error every 1° up to 10° (See Fig. 4).

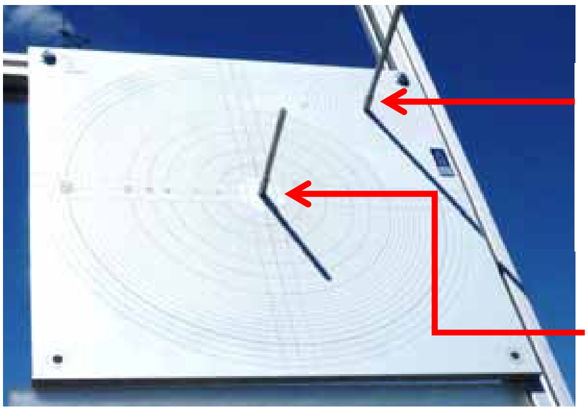


Figure 4: Shade stick to calibrate solar tracker

Once the tracker is correctly oriented, the tracker is set on an automatic tracking mode. The correct elevation at the initial point is finally checked with the theoretical solar elevation calculated and compared with the digital inclinometer measurement.

The tracking error $\Delta\alpha_{track}$ is calculated from the tracker inclination measured by the digital inclinometer α_{INCLI} and from the solar elevation α_S calculated using the Blanco et al. (2001) algorithm as described in the equation 1.

$$\Delta\alpha_{track} = \alpha_{INCL} - (90 - \alpha_S) \quad \text{(eq. 1)}$$

Fig. 5 shows an example of the measurement of the digital inclinometer. The angle to be compare to the solar elevation is 90-α_S because the tracker is perpendicular to the solar direction.

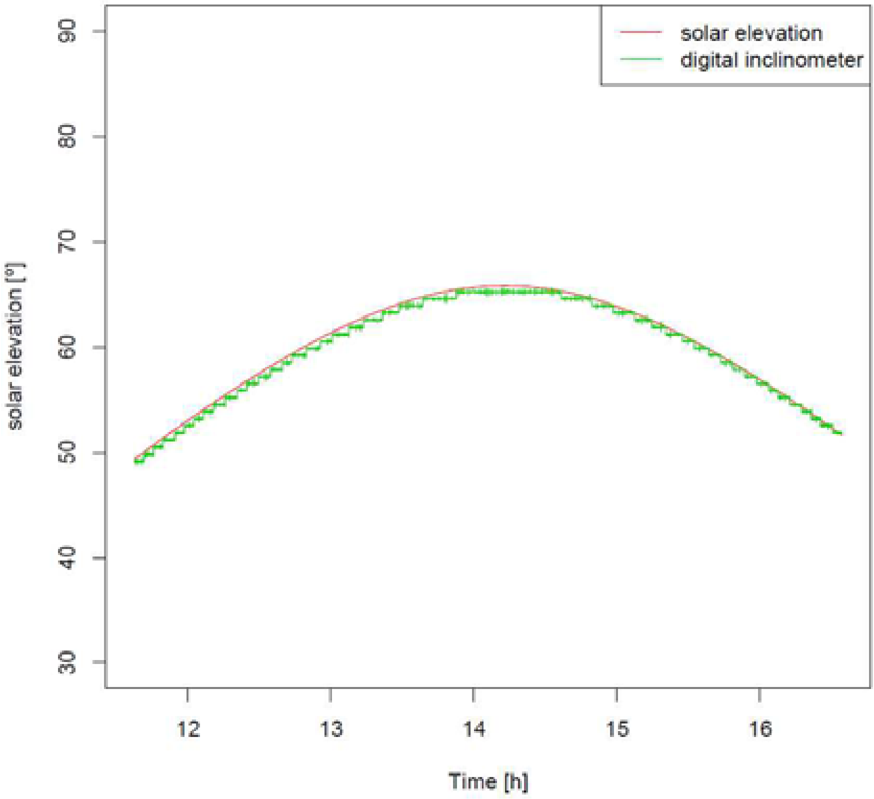
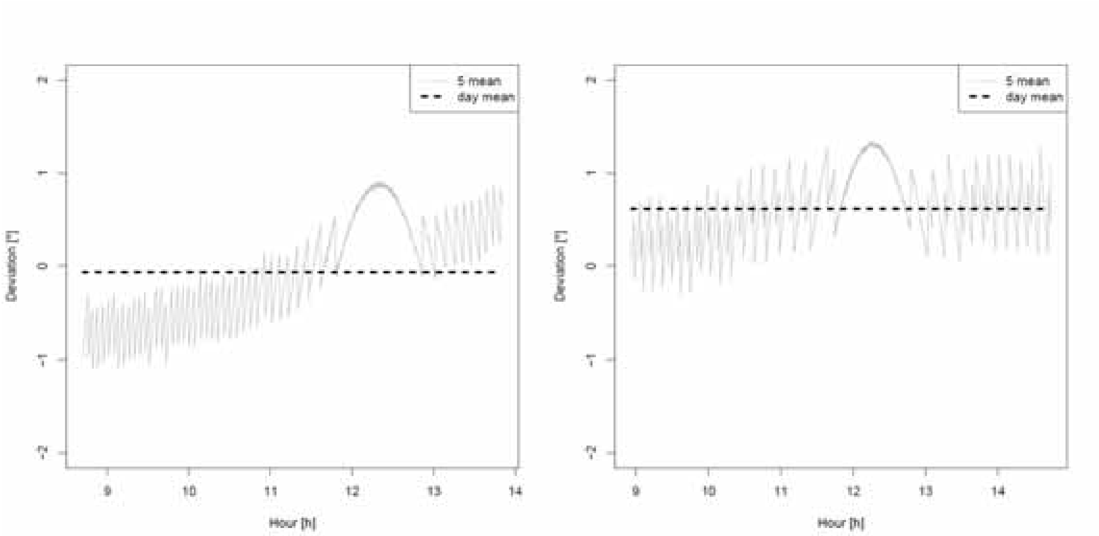


Figure 5: Exemple of solar elevation and inclinometer measurement comparison

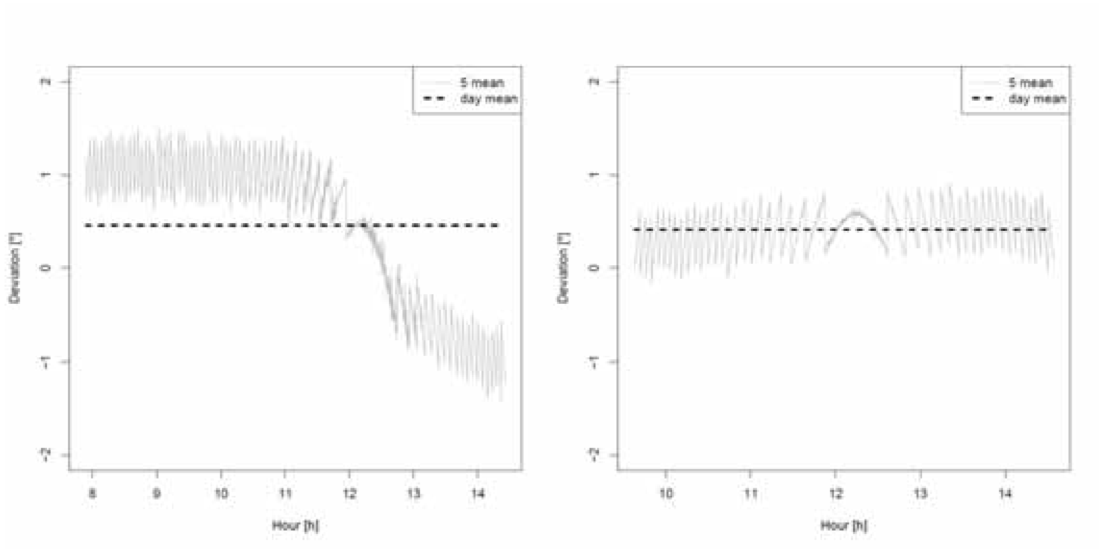
4. Results and discussion

4.1. Tracker elevation accuracy estimation

The results of the measurement are presented in Fig. 6. A clear difference is observed between the morning and the afternoon. This difference could be caused by the time synchronization of the tracker or some azimuth deviation of the solar tracker. This measurement pattern is not always equal because the initial solar tracker position and its clock were adjusted differently every day, so those possible errors vary from day to day



(a) **(b)**



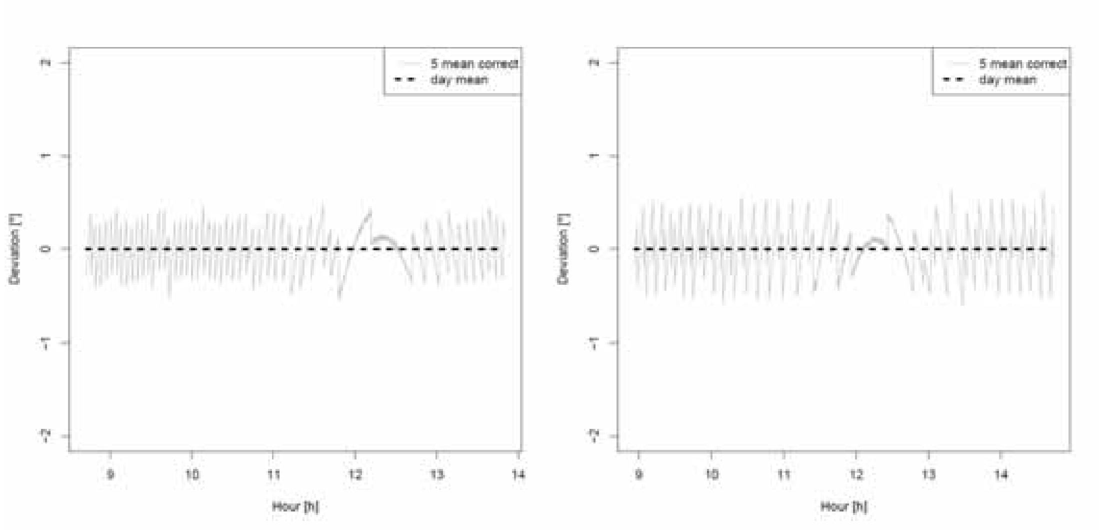
(c) **(d)**

Figure 6: Inclination measurement error on solar tracker: (a) 22/07/2013 (b) 23/07/2013 (c) 24/07/2013 and (d) 29/07/2013

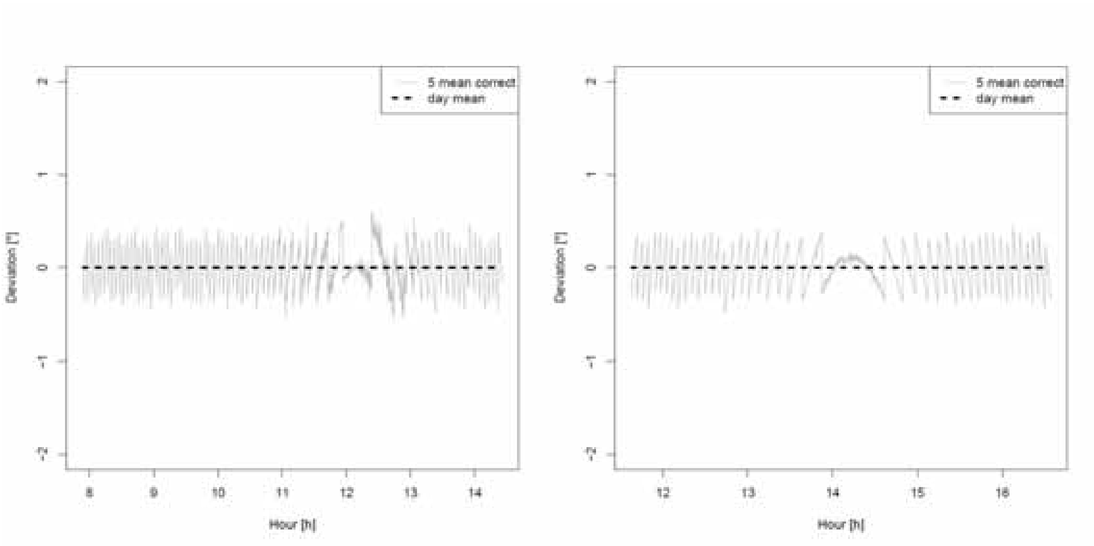
The mean value of the tracking deviation $\Delta\alpha_{track}$ during the whole 4 testing days is 0.38º, with a minimum value of -2.12º and a maximum value of 3.16º and, out of extreme values, the tracking deviation in elevation is within ±2º, even less (See Fig. 7a). The standard deviation of the tracking deviation is 0.60º.

But as the deviation tendency varies throughout the day, due to azimuth error or clock imperfect synchronization of the solar tracker control, a correction is applied in order to analyze only the oscillation of the solar tracker without those effects. The mean value of the instantaneous tracking deviation $\Delta\alpha_{track}$ was calculated every 30 mina, $\Delta\alpha_{track\_m}$. Then, the instantaneous tracking error was corrected by subtracting the mean value such as: $\Delta\alpha_{track\_cor} = \Delta\alpha_{track} - \Delta\alpha_{track\_m}$.

The results of this correction are presented in Fig. 7.



(a) **(b)**

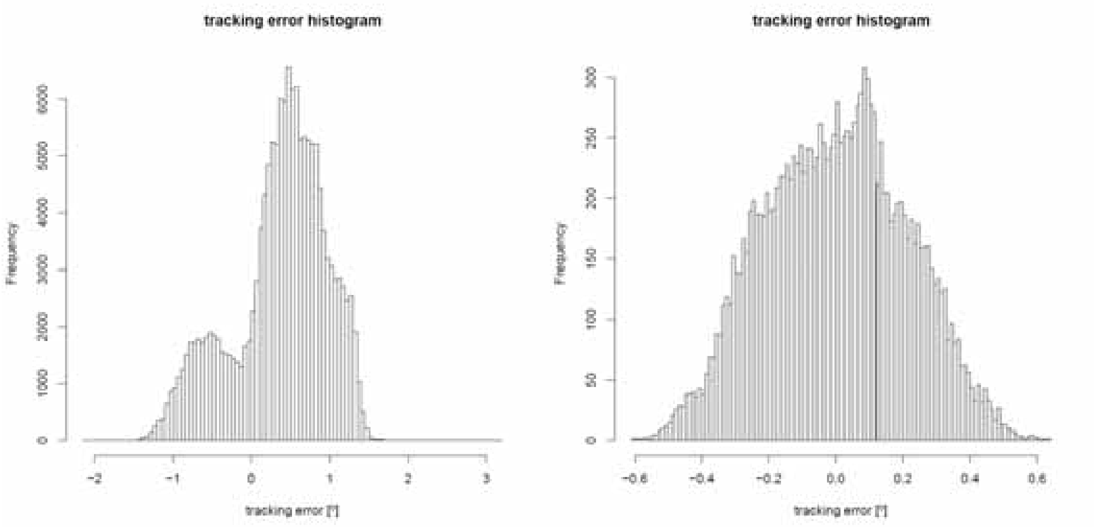


(c) **(d)**

Figure 7: Corrected inclination measurement on solar tracker: (a) 22/07/2013 (b) 23/07/2013 (c) 24/07/2013 and (d) 29/07/2013

The mean value of the corrected tracking deviation $\Delta\alpha_{track\_cor}$ during the whole 4 testing days is almost 0º (-1.23 10^{-18} which was expected as already corrected over the 30 min interval). The minimum value obtained was -0.60º and maximum value was 0.63º (See Fig. 7). The standard deviation of the tracking deviation $\Delta\alpha_{track\_cor}$ is 0.21°. The corrected tracking deviation in elevation is within ±0.6º.

Fig. 8 shows the distribution of the tracking deviation with and without the correction.



(a) **(b)**

Figure 8: histogram error frequency of the tracking error (a) not corrected value (b) corrected value every 30 min.

The distribution of the net tracking deviation is not normal $\Delta\alpha_{track}$ and has two different tendencies: a negative and a positive one. The distribution of the correct tracking deviation $\Delta\alpha_{track\_cor}$ seems like a Gaussian distribution (Fig. 8b).

5. Conclusions

The tracking elevation deviation measured along 4 testing days using a digital inclinometer is presented in this paper. The mean tracking deviation was of 0.38º and the maximum tracking deviation was of 3.16º. Most of the time, the tracking deviation in elevation is within ±2º. But considering an offset error due to the solar tracker orientation or clock control, a correction was calculated to correct the tracker precision over 30 min period. The corrected tracking deviation in elevation, the oscillation tracking, is within ±0.6º

When comparing with the acceptance angle of different solar concentrators, we can consider that this solar tracker could be used with the medium temperature collectors Solitem, Solar Kinetics Inc or IST (see Table 1).

In order to improve the precision of a low cost solar tracker, a correction could be implemented on the tracking algorithm to compensate the systematic errors observed. Thus, the results could be improved by a third, reducing the tracking error from ±2° to ±0.6° as seen in this paper.

In future studies, the orientation of the solar tracker will be also checked, and the optical losses of the concentrator due to the tracking deviation will be calculated, to see the impact of this tracking deviation on the collector production.

6. Acknowledgements

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7. References

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