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Analysis of Total Station Real Time Atmospheric Correction Model in FAST Measurement

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ABSTRACT

As the most important feedback source of the FAST telescope control system, the measurement system directly determines the overall performance and observing efficiency of FAST. High-precision total station measurement equipment is used in real-time measurement of the FAST reflector and the feed cabin. Because the measurement accuracy of total station is easily influenced by the atmospheric environment, in this paper, we established the distribution model of temperature, humidity and pressure through the meteorological information collected by the weather stations evenly distributed in the reflector. We analyzed the changes of atmospheric environment caused by FAST topography and calculated the real-time atmospheric correction at each location within the coverage of the weather station based on the formula. Finally, according to the variation of the atmospheric correction value in the measurement path, the optimal atmospheric correction parameter of the path is obtained, so as to improve the measurement accuracy of the FAST reflector.

Keywords: FAST, PPM, total station, measurement

1. INTRODUCTION

Precise measurement and control is the key to achieving good observation performance of the FAST. From the current FAST debugging results, high-precision measurement is the technical difficulty and bottleneck of the entire system. The feed cabin and reflector measurement of FAST all use high-precision total station equipment. Total station has high-precision angle and distance measurement function, the accuracy of the angle measurement accuracy can reach 0.5" and the measurement accuracy can reach 0.6mm+1ppm. It has been widely used in the field of precision engineering, but it is mainly used in static precision measurement. In order to ensure the static and dynamic tracking measurement accuracy of FAST reflector and feed support measurement in outdoor large-scale environment, it is necessary to analyze and correct the influence of the error source of the total station. The main error source for total station measurement is the atmospheric refraction error^[1]. Therefore, how to effectively obtain the characteristics and rules of atmospheric correction, correct the atmospheric refraction error, and then reasonably design and optimize the measurement program is the key to FAST precision measurement.

The total station is a kind of precision measuring instrument integrating light, machine and electricity. It can simultaneously realize high-precision angle (horizontal angle, vertical angle) measurement, distance (slant distance, horizontal distance, height difference) measurement and data processing. The electronic distance measurement function of the total station is to use photoelectric technology to calculate the measurement distance by measuring the propagation time of light waves on the measurement section. However, due to the environmental changes of the external meteorological changes and the cover of the surface vegetation, the total density of the total stations in the observation path is not exactly the same, resulting in different atmospheric refractive index, which affects the accuracy of distance measurement. At the same time, changes in air density will also cause vertical and horizontal refraction effects, which will cause errors in the angle measurement of the total station. The error caused by atmospheric refraction is a common problem encountered in near-ground outdoor precision engineering surveys. Therefore, the meteorological correction of the observation distance must be performed based on the observed temperature, humidity, and atmospheric pressure.

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$$\Delta D_1 = 286.338 - \left[\frac{0.29535 \cdot p}{(1 + \alpha t)} - \frac{4.126 \cdot 10^{-4} \cdot h}{1 + \alpha t} \cdot 10^x \right] \quad (1)$$

$$x = (7.5 \times t / (237.3 + t)) + 0.7857$$

$$\alpha = 1 / 273.15$$

p -atmosphere pressure (mbar)

h -humidity (%)

t -temperature($^{\circ}$ C)

ΔD_1 -Atmospheric refraction correction (ppm)

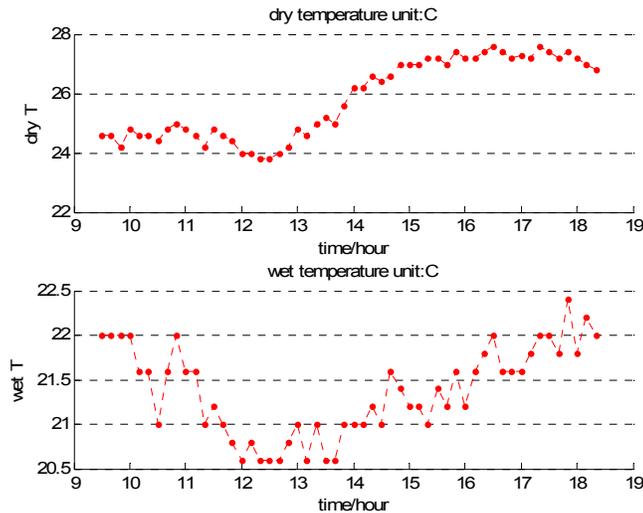
In this paper, we will first analyze the results of the atmospheric correction experiment and evaluate the influence of atmospheric refraction on the accuracy of the total station's ranging. Then combined with the special geomorphic environment of the FAST site to establish an atmospheric correction model that conforms to the site environment to reduce the atmospheric refraction error and provide an effective solution for improving the measurement accuracy of the total station.

1. Atmospheric correction experiment

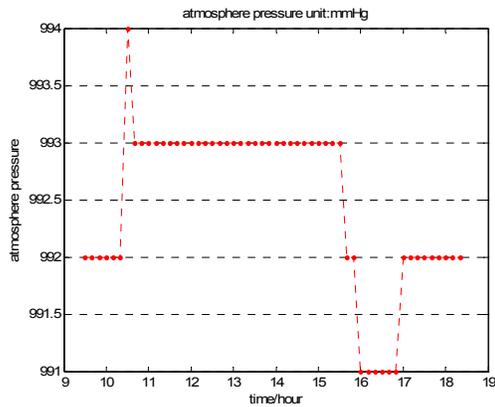
The experimental site is a standard baseline field. Refer to the total station measurement distance in the FAST reflector and feed cabin measurement, the lengths of the selected fixed baselines were: 183.0823m, 285.1647m, 369.8525m, 479.1924m, 623.6396m. Each baseline is measured at regular intervals of 10 minutes and measurements are repeated 5 times for each measurement. The attainment of atmospheric parameters is consistent with measurement time. The measurement lasted for more than 8 hours to analyze the characteristics of daytime atmospheric correction.

In the experiment, the total station measurement used a precision measurement mode, and the weather station were measured near the total station. The identification accuracy of the weather station is: temperature: 0.2 $^{\circ}$ C, pressure: 0.5 mbar, which can meet the experimental accuracy requirements.

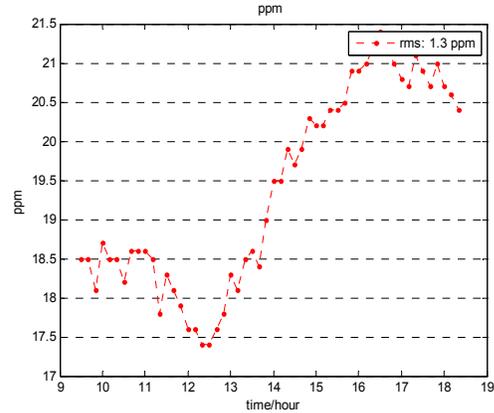
Take an experiment data as an example, as shown in Fig. 1 (a, b, c), and calculate the corresponding atmospheric correction value PPM according to formula 1.



(a) dry temperature and wet temperature



(b) pressure



(c) Atmospheric correction(ppm)

Figure 1 Atmospheric parameters and atmospheric corrections

The correlation between atmospheric corrections and atmospheric parameters was analyzed. The results are shown in Fig. 2. It shows that the correlation between atmospheric refraction and dry temperature is the strongest, followed by wet temperature, and once again atmospheric pressure. It can be seen that there is a certain time delay between the atmospheric correction and the wet temperature.

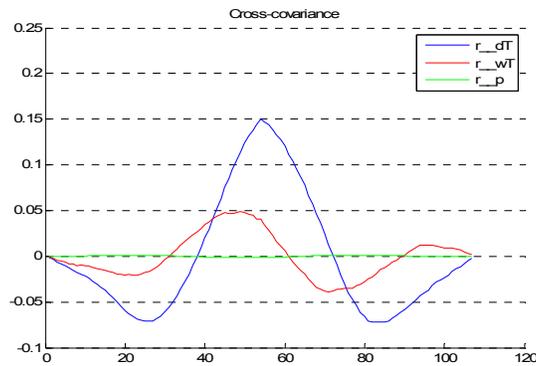


Figure 2 Correlation between Atmospheric Correction and Atmospheric Parameters

The results of the five experiments were analyzed and the atmospheric corrections were performed. The results are shown in Table 1. The standard deviation of the baseline observation length from the theoretical value was 0.7 mm. Using the meteorological parameters, the accuracy of atmospheric refraction correction was improved to 0.16 mm.

Table 1 The accuracy of atmospheric correction

Time	Baseline theoretical value/m	Distance measurement error /mm	Corrected distance measurement error /mm
9:30-18:30	623.6396	0.9	0.2
8:00-19:00	285.1647	0.3	0.1
8:30-17:30	183.0823	0.6	0.1
8:10-18:20	369.8525	0.9	0.2
9:10-17:00	479.19245	0.8	0.2
Average value		0.7	0.16

As shown in Figure 3 (a, b), the measured distance and change of the baseline (623.6396m), the distance observation accuracy is 0.9mm, and the accuracy after atmospheric refraction correction is improved to 0.2mm.

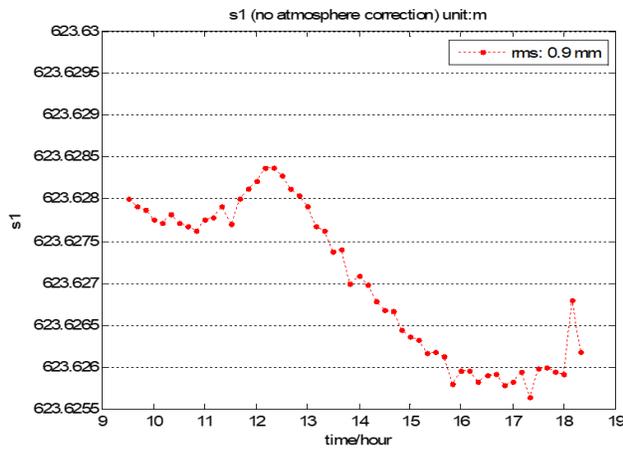


Figure 3.a The measured distance of baseline

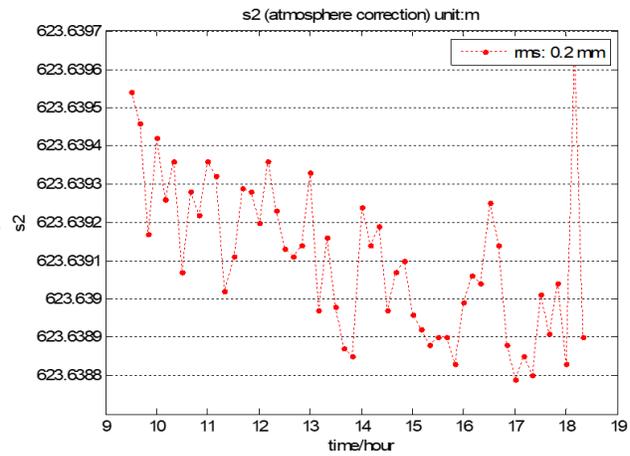


Figure 3.b The distance after atmospheric correction

2. Establish FAST Atmospheric Correction Model

Compared with the existing international giant single dish radio telescope, FAST have three independent innovations^[2]:

1. The karst depression used as the site(Fig.4), which is large to host the 500-meter and deep to allow a zenith angle of 40 degrees;
2. The active main reflector correcting for spherical aberration on the ground to achieve a full polarization and a wide band without involving complex feed systems;
3. The light-weight feed cabin driven by cables and servomechanism plus a parallel robot as a secondary adjustable system to move with high precision.

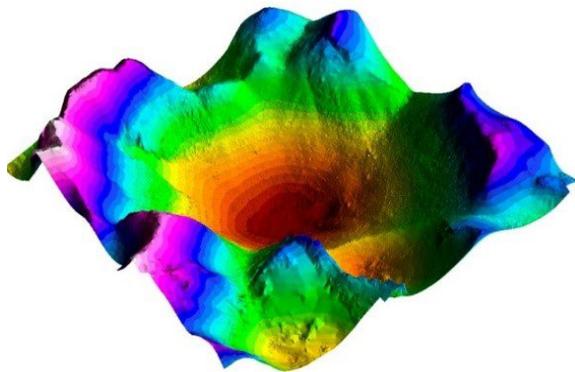


Figure 4 FAST topographic map

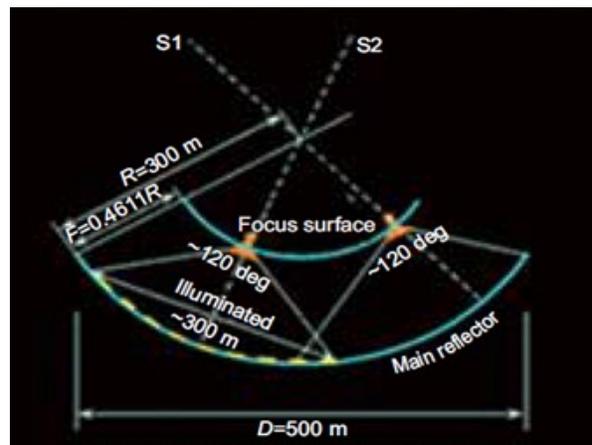


Figure 5 FAST optical geometry

Six suspension cables are driven and supported by six towers and capstans which are uniformly distributed on a circle with a diameter of 600m. Feed cabin dragged by six suspension cables, realized the feed cabin in 150meters altitude 206 meters' diameter range of movement. The maximum height difference of FAST reflector is 140m and the maximum width is 500m.(Fig.5)

Based on the results of the previous experiments, combined with the topography of the FAST site, We selected 10 control points in the FAST precision measurement control network to install weather stations and measure the meteorological information of the stations in real time. According to the meteorological information collected in real time, the distributed field model of temperature, humidity, and pressure was established using a three-dimensional interpolation method. Then according to formula 1, calculate the atmospheric correction value corresponding to each point inside the reflector. It should be noted that since the installation of the weather station does not completely cover the FAST reflector, the currently used method can only obtain the relevant meteorological parameter distribution model within the coverage of the weather station. This is also the problem that we need to solve in the next step.

We selected data recorded at 12:00 am for temperature, humidity, and pressure (Figure 6). It can be seen that the maximum value of the atmospheric correction is 6 ppm. If not use the atmospheric correction and the distance is 300 m, the distance error will be close to 2 mm, which will seriously affect the accuracy of the FAST reflector measurement.

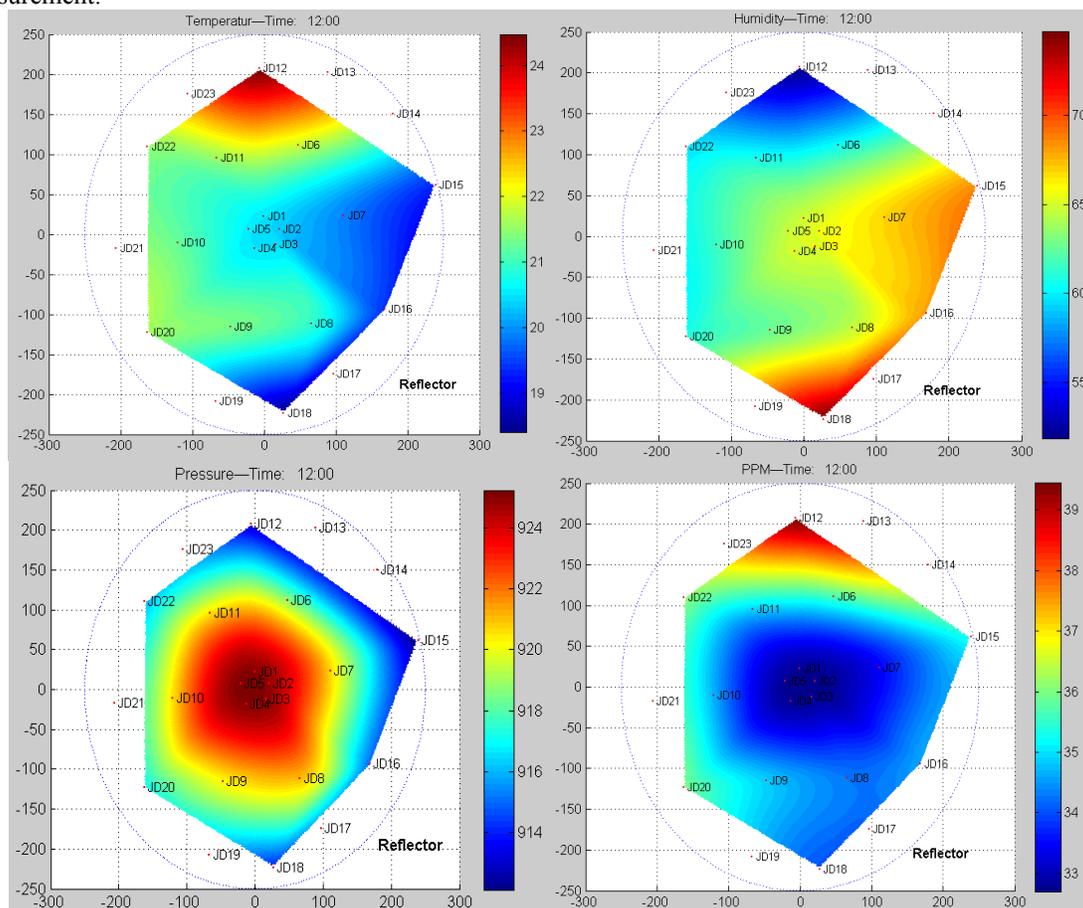


Figure 6 FAST site temperature, humidity, pressure and atmospheric correction distribution (am 12: 00)

The FAST site is surrounded by mountains. From morning to night, as time changes, the place where the FAST reflecting surface can reach the sun gradually changes, and the temperature and humidity also change regularly, and the pressure change is small. Due to the temperature difference between day and night and the large variation in

humidity, the range of PPM changes is relatively large. If atmospheric correction is not performed, the accuracy of measurement will be greatly affected. We compared and analyzed the changes of the atmospheric correction values at each position caused by changes in meteorological parameters at different times of the day. Choose four times that are representative of the weather: 4:00, 8:00, 12:00, and 16:00. Calculate the distribution of atmospheric corrections corresponding to each moment, as shown in Figure 7. According to the comparison, the atmospheric correction errors caused by meteorological parameters at different times in the same location can reach 10 ppm.

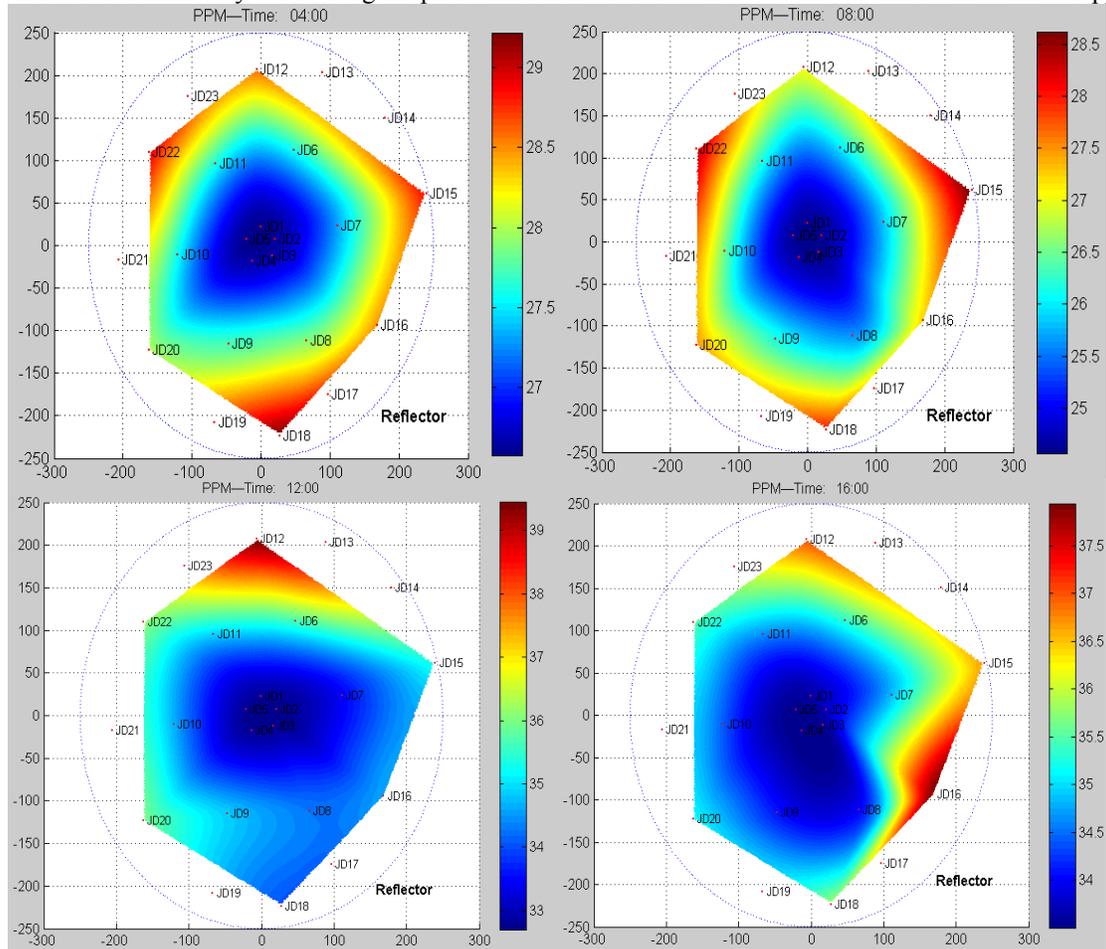


Figure 7 the distribution of atmospheric corrections at different times

3. Summary and conclusions

Through the analysis of this paper, we can see that real-time atmospheric correction can greatly reduce the measurement error. Since the meteorological parameters of the measurement signal propagation path cannot be measured in the entire path during the observation process, the meteorological parameters (or the median of two locations) of the measurement station or mirror station are currently used for atmospheric refraction correction, but the distance is far away. The target, the meteorological parameter of the observation path changes greatly, still will have the error. Therefore, in order to further improve the measurement accuracy, we still need to establish a meteorological parameter distribution model that covers the range of motion of the reflection surface and the feed cabin, and perform accurate estimation and modeling of the changes in the meteorological parameters of the full path.

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