Tersus ExtremeRTK™ Technology

White Paper

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Abstract

This white paper discusses the latest ExtremeRTK™ technology from Tersus GNSS Inc. This technology integrates Tersus GNSS receiver's hardware, GNSS high precision baseband IC, RTK algorithm, etc. in order to obtain unprecedented stability performance in extreme harsh environment and fundamentally eliminate the occurrence of occasional RTK positioning outliers. This technology mainly includes the following aspects.

- Tersus' self-developed GNSS high-precision baseband IC tracking algorithm with strong resistance to pseudorange and carrier phase multipath, and strong suppression of reflected multipath from buildings/water/ground, and scattered multipath under trees.
- Tersus' RTK algorithm does a comprehensive check of the ambiguity search results in multiple dimensions, including aperture domain, residual domain, global time domain, etc., ensuring that each group of accepted ambiguity has a high degree of confidence.
- Tersus' RTK does a comprehensive comparison of each accepted set of ambiguities relative to a large number of other ambiguities (several hundreds), ensuring that each accepted ambiguity set is optimal over a sufficiently large space.
- Tersus' GNSS boards have the capability to record raw observations, including raw RTCM data and baseband trace output results.
- Tersus' test department has a database of thousands of test cases in a variety of harsh scenarios, and this database continues to expand, with each version update iteration requiring the case to be tested and approved before it can be released.

Tersus' latest ExtremeRTK™ technology provides a more reliable solution for a wide range of applications in surveying and mapping, precision agriculture, UAVs, autonomous vehicles, robotics, and more.

Figure 1 BX40C board

Figure 2 Oscar GNSS Receiver (Ultimate)

Test Plan

The data in this paper comes from the Tersus ExtremeRTK^{TM} technology research and development team. The base station used for the test is broadcasted by Tersus and the mainstream Qianxun CORS service, and the differential data format is RTCM3.2. The test scenarios include open sky, half-covered sky, dense forest and urban canyon, etc. The actual pictures of the test scenarios will be provided in each subsequent test item.

The main test contents are as follows.

(1) Time to First Fix (TTFF)

(2) Continuous observation stability at fixed points

(3) Multi-time RTK reset accuracy

(4) Multi-path effect suppression capability

(5) Tilt measurement test, including initialization time, state holding time, measurement accuracy in open sky and extreme obscured environment

Table 1 Test overview

Test item / Test conditions	TTFF	Continuous observation stability at fixed points	Multi-time RTK reset accuracy	Multi-path effect suppression	Tilt measurement			
					Initialization time	State holding time	Multi-angle accuracy	Accuracy in extreme obscured environment
Base station	Tersus	Tersus	Tersus	Tersus	Tersus	Tersus	Tersus	Qianxun
Baseline	15km	15km	5km	5km	5km	5km	5km	VRS
Scenario	Open sky	Open sky / severe obstruction	Open sky	Open sky	Open sky	Open sky	Open sky	Severe obstruction
Test method	GPGGA	RMS	RMS	Zero baseline	Time statistics	Time statistics	RMS	RMS

Time to First Fix (TTFF)

In order to truly and accurately present ExtremeRTK™ fixed speed, our test adopts Tersus base station, baseline distance of 15km and open sky environment. We use the state identifier in the GPGGA statement, count the duration from state 2 (code difference) to state 4 (fixed) after a single RTK initialization, and use the RTK reset command for 59 times totally, in which RTK reset is to redo RTK initialization to get fixed operation through the board command. The statistics show the BX40C TTFF fixed time in figure 3. It can be seen that **in this condition, the shortest TTFF is about 2s, the longest is about 3s, and the average time is 2.29s**, which truly reflects the excellent performance of getting fixed in seconds by ExtremeRTK™ technology.

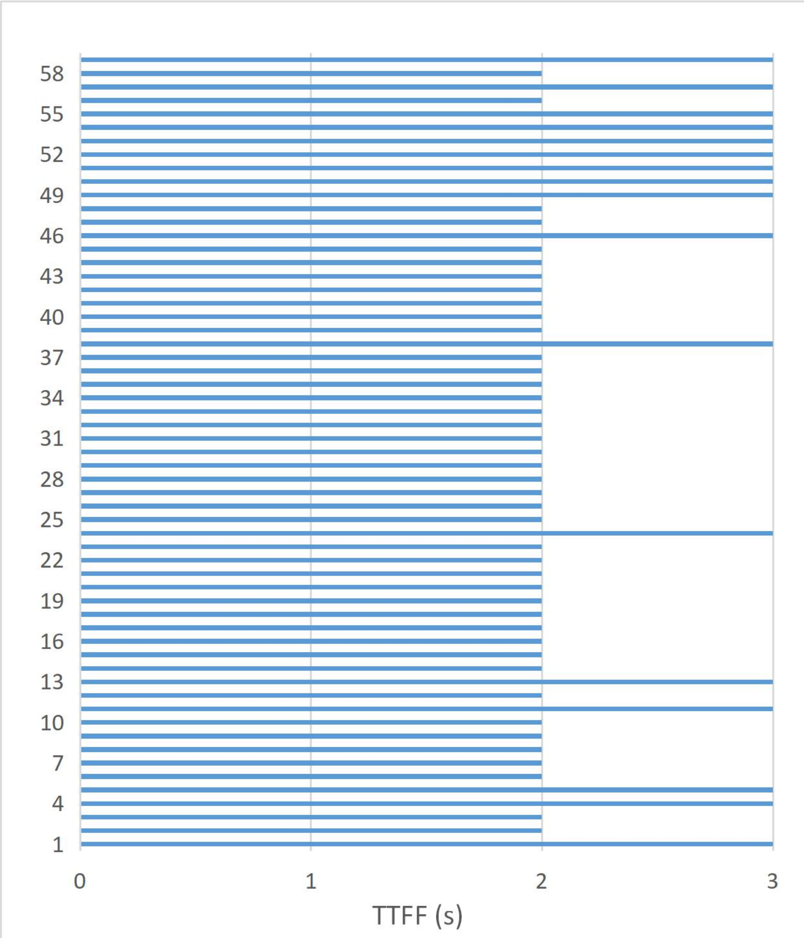

Figure 3 TTFF at 15km baseline

Continuous observation stability at fixed points

To obtain intuitive continuous measurement accuracy stability of ExtremeRTK™ technology, two scenarios of open sky and severe obstruction are for test environment. Our test adopts Tersus base station, baseline distance of 5km, acquisition interval of 5s, continuous observation of 1200 points and lasts around 1.7 hours. Then we calculate the RMS value of plane and elevation. From Figure 4, in the open sky environment, the plane error of 1200 points in 1.7 hours is only 0.64cm and the elevation error is only 1.44cm; from Figure 5, in the severe obscured environment (10-story building and dense forest environment), the plane error of 1200 points in 1.7 hours is only

2.40cm and the elevation error is only 3.08cm; thus we can reasonably believe that ExtremeRTK™ is fully capable of measuring in any scenario.

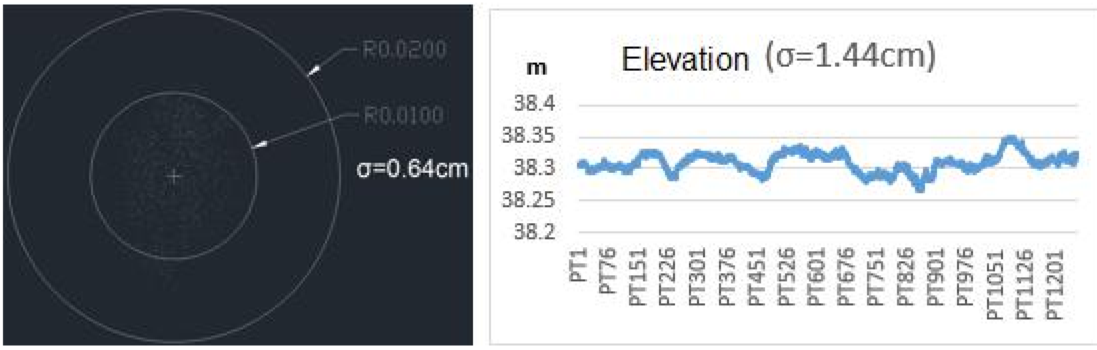

Figure 4 Continuous RMS in open sky

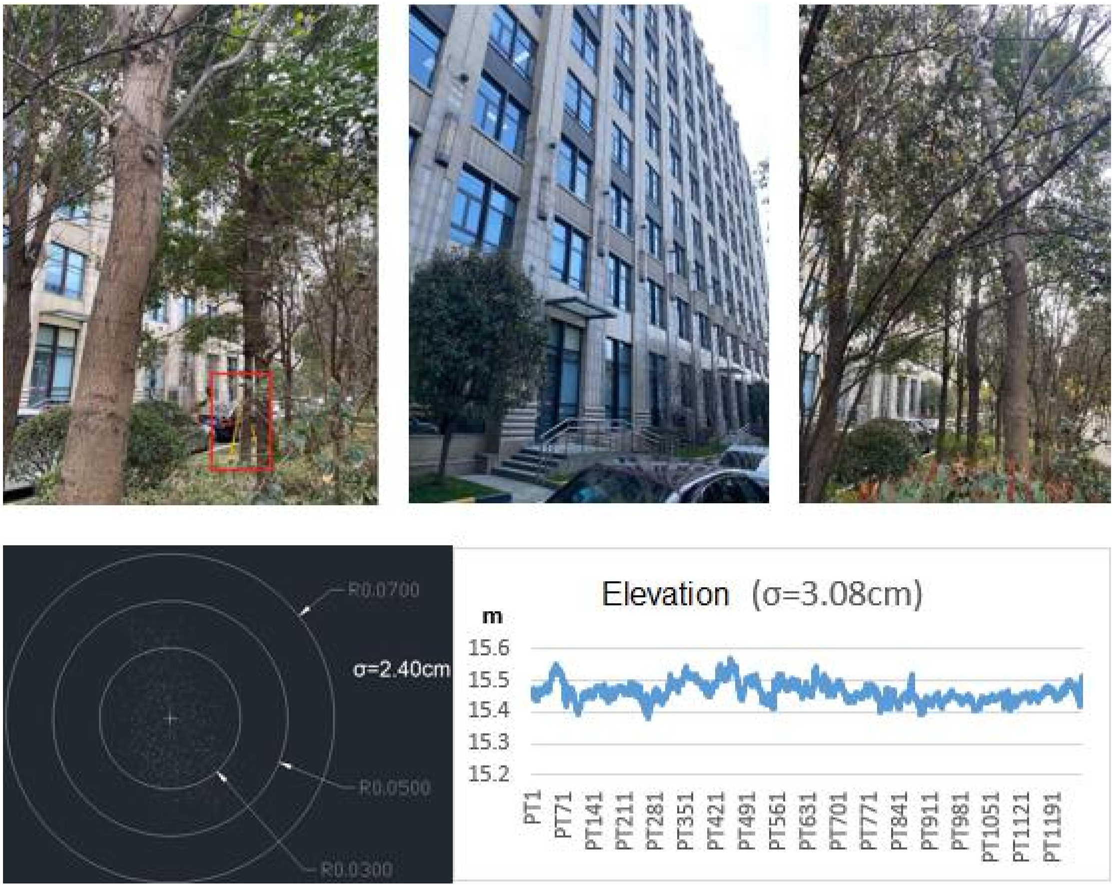

Figure 5 Continuous RMS in severe obstruction

Multi-time RTK reset accuracy

With the continuous maturity of RTK technology, many cities have now allowed the use of RTK for control measurement. Taking DG/TJ08-2121-2013 "Shanghai Engineering Construction Specification - Technical Specification for Satellite Positioning Measurement" as an example, the specification stipulates that RTK plane control measurement should be carried out after RTK fixation, each point should be independently initialized twice, two sets of data should be collected each time, the plane point difference of four sets of data should be less than 2cm. Repeat sampling check should be carried out on the next day or near the time of collection ending, and the difference between repeat sampling and initial collection should be less than 3cm. The specification stipulates that RTK geodetic height control measurement should be carried out after RTK fixation, and each point should be initialized four times independently, with two sets of data collected each time, and the difference between the point elevation of four sets of data is less than 3cm. Repeat sampling check should be carried out on the next day or near the time of collection ending, and the point elevation difference between the repeated sampling collection and the initial collection should be less than 5cm.

Refer to Shanghai GNSS control measurement specification, we adopt Tersus 5km baseline and design a test of four time periods in total lasting three days 2021-02-23 12:57:13- 2021-02-23 13:04:34 (period 1), 2021-02-24 09:24:43- 2021-02-24 09:32:17 (period 2), 2021-02-24 14:18:50- 2021-02-24 14:26:13 (period 3), 2021-02-25 09:37:10- 2021-02-25 09:44:16 (period 4), in each time period initialize the receiver eight times, collect two sets of data during each initialization, collect 16 sets of data in a single time period, collect 66 sets of data in total of four periods. From Figure 6, the plane mean square error in period 1 is 0.32cm and the elevation mean squire error is 0.42cm, in which the maximum difference of plane point position in this period is 0.83cm and the maximum difference of elevation is 1.32cm; from Figure 7, the plane mean square error in period 2 is 0.25cm and the elevation mean square error is 0.39cm, in which the maximum difference of plane point position in this period is 0.79cm and the maximum difference of elevation is 1.32cm; from Figure 8, the plane mean square error in period 3 is 0.35cm, the elevation mean square error is 0.78cm, in which the maximum difference in the plane point is 1.24cm, and the maximum difference of the elevation is 2.68cm; from Figure 9, the plane mean square error in period 4 is 0.29cm, the elevation mean square error is 0.96cm, in which the maximum difference in the plane point is 0.85cm, and the maximum difference in the elevation is 2.66cm; from Figure 10, the plane mean square error in four periods is 0.66cm, the elevation mean square error is 0.74cm, in which the maximum difference in the plane point is 2.66cm, and the maximum difference in the elevation is 3.66cm. **Under the premise of more stringent observation conditions than those required by the Shanghai specification, the difference between the single period and the mean square error in each period meet the specification requirements.**

Figure 6 Observation RMS of plane and elevation in period 1

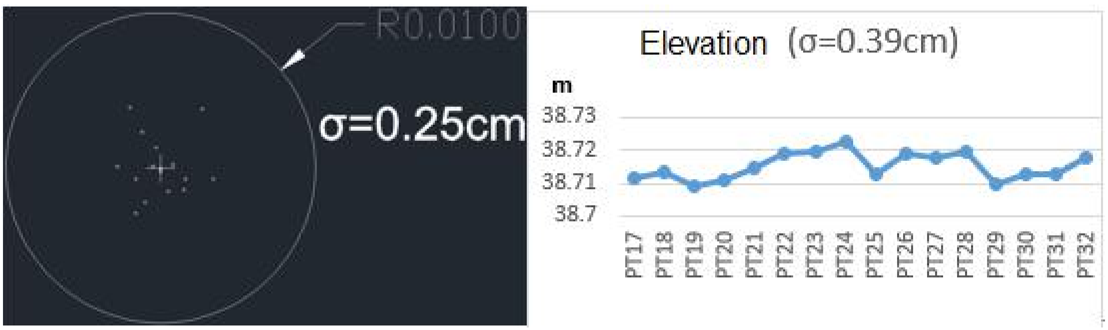

Figure 7 Observation RMS of plane and elevation in period 2

Figure 8 Observation RMS of plane and elevation in period 3

Figure 9 Observation RMS of plane and elevation in period 4

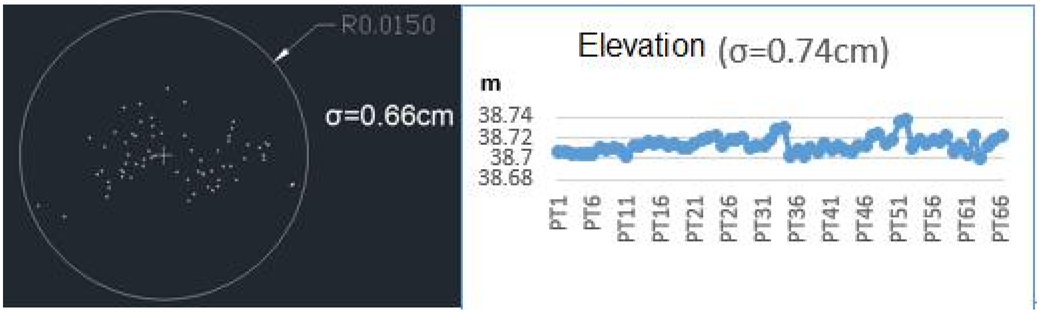

Figure 10 Observation RMS of plane and elevation in all periods

Multi-path effect suppression capability

After double difference principle modeling of RTK, most of the errors such as clock difference, ionospheric delay, tropospheric delay, etc. have been eliminated or significantly reduced, so the main work is focused on multi-path error estimation and suppression. ExtremeRTK^{TM} creatively adopts new solutions, significantly reduces the impact of multi-path effects. In this test, we use zero baseline test method, the same observation signal is introduced into receiver brand A, Tersus BX40C, receiver brand B, and receiver brand C. REC1, REC2 (BX40C), REC3, and REC4 are subsequently used for short of the four different brands of receivers. Figure 11 and 12 give the pseudorange multi-path statistics of REC1, REC2 (BX40C), REC3, REC4 receivers respectively, where the horizontal coordinates indicate GNSS satellite frequencies and the vertical coordinates indicate multi-path errors, the smaller the error the better the performance; Figures 13 to 15 give a comparison of the carrier multi-path suppression effect of REC1, REC2 (BX40C), REC3 receivers, in which the sky map corresponds to the different satellite altitude angles of GPS, GLONASS, Galileo, and BDS constellations in turn, and the lighter color (green) means better performance. **It can be seen that Tersus BX40C has stronger multi-path error suppression capability at each frequency, especially for BeiDou satellites.**

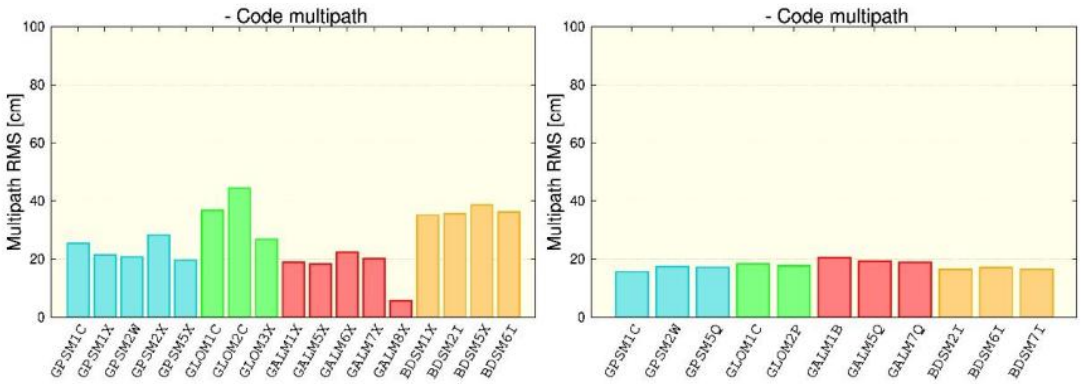

Figure 11 Pseudorange multi-path statistics of REC1 and REC2

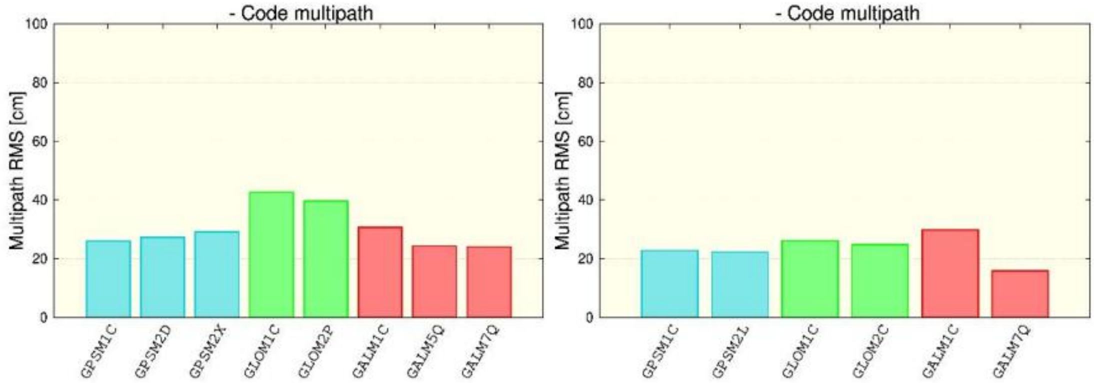

Figure 12 Pseudorange multi-path statistics of REC3 and REC4

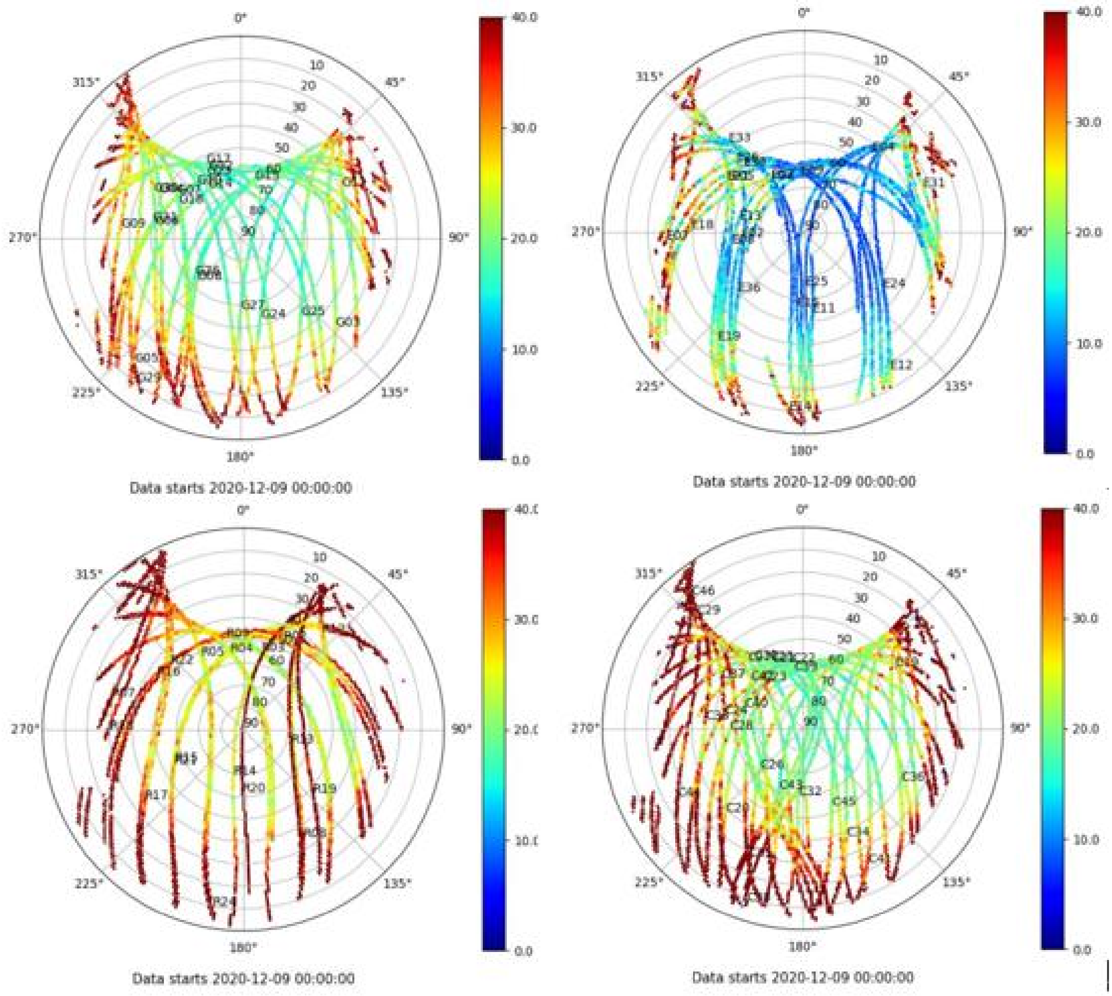

Figure 13 The carrier multi-path error sky map of REC1

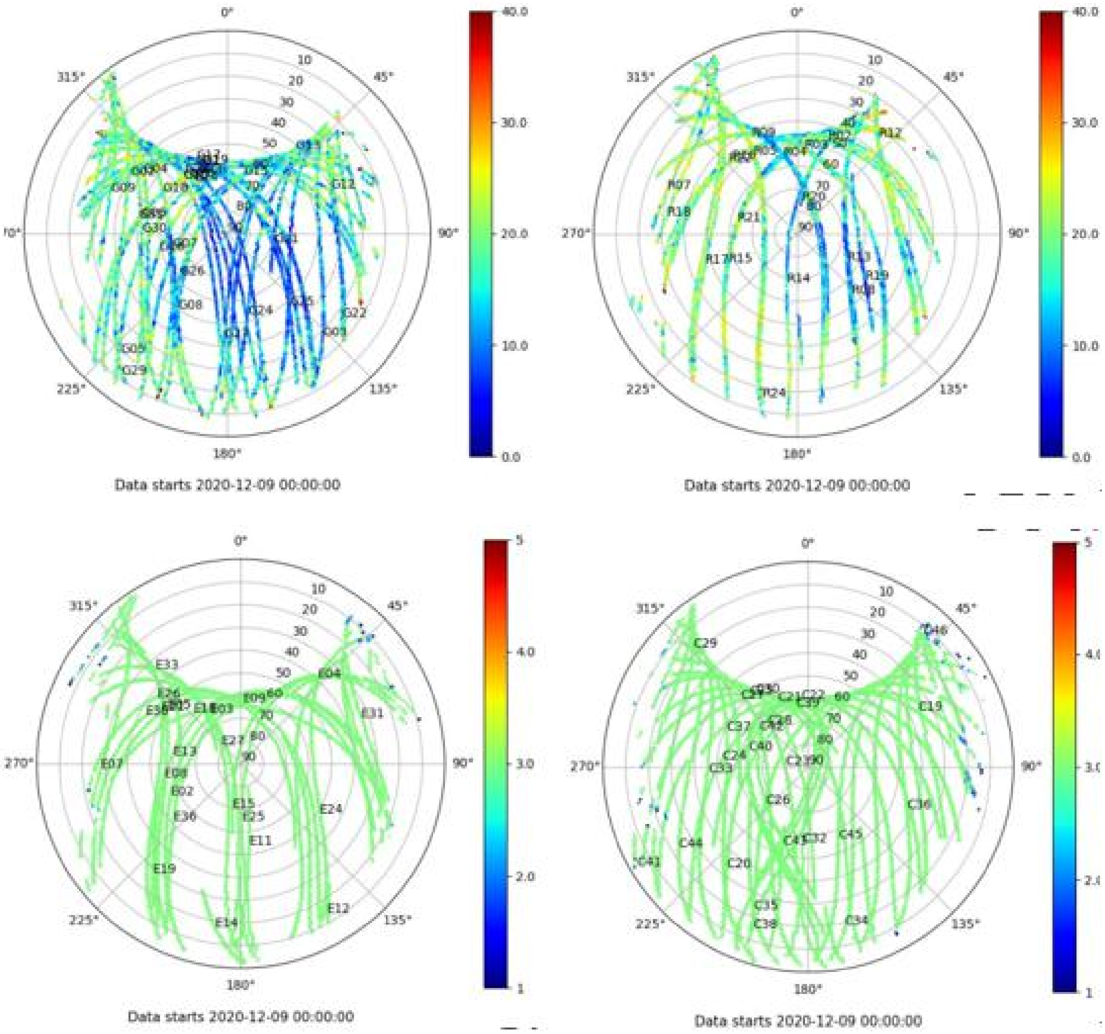

Figure 14 The carrier multi-path error sky map of REC2 (BX40C)

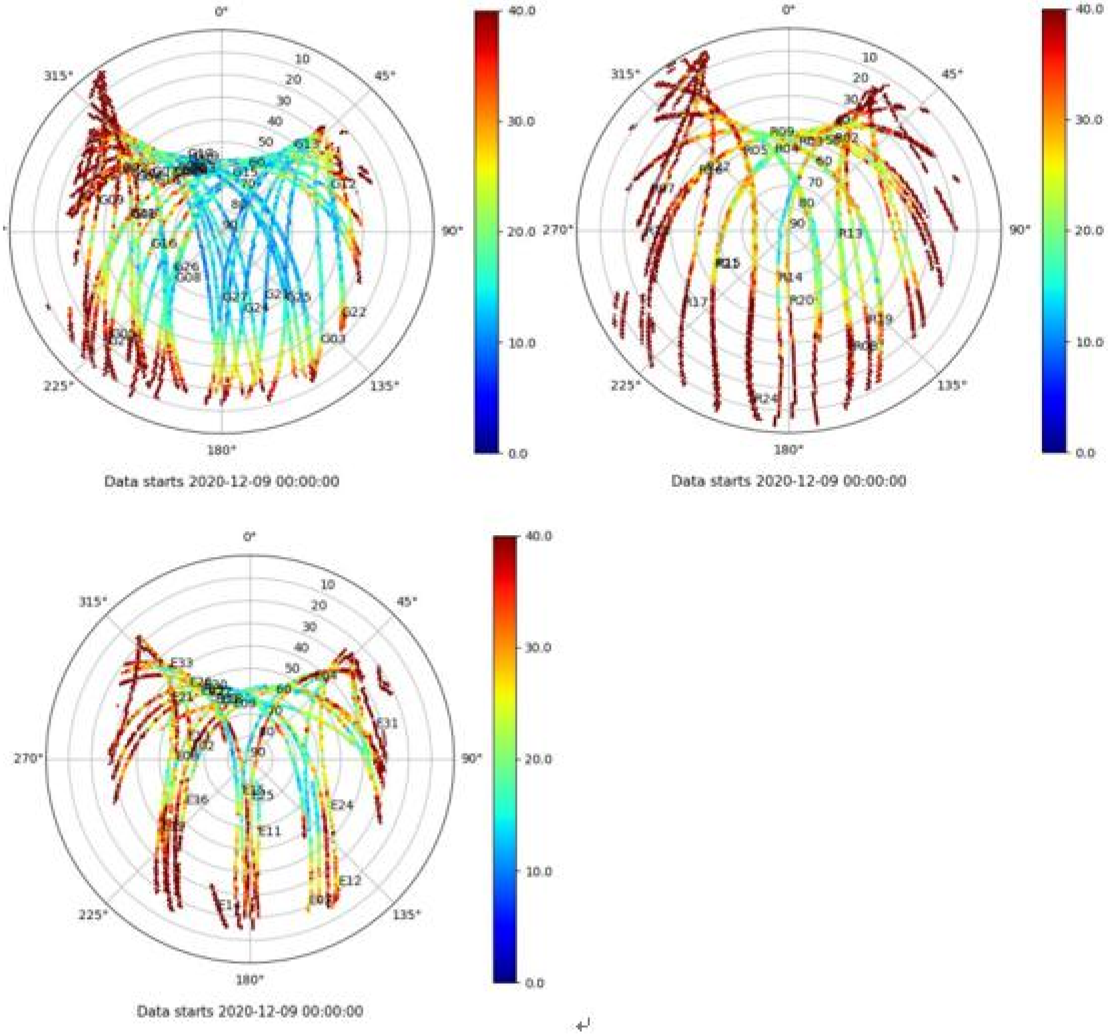

Figure 15 The carrier multi-path error sky map of REC3

Tilt measurement test

Initialization time

From the market research, it is found that the fast initialization time is one of the most important elements for users' concern. Looking back at the development of tilt measurement, the first generation of tilt measurement solutions have been gradually abandoned due to the extensive use of strong magnetometer, resulting in serious impact by the surrounding geomagnetic environment. ExtremeRTK receiver is based on the latest high-performance IMU, completely abandoning the traditional solution based on geomagnetic decoding, completely immune to magnetic interference. With ExtremeRTK™ technology, we can truly achieve the measurement without shaking in advance. **According to the actual test, ExtremeRTK receiver tilt initialization time is only 5~15s**. Please refer to the following initialization test video for more details.

Video link: https://youtu.be/Pr5eFV8WNtc

Tilt state holing time

In order to solve the problem of easy loss of tilt compensation state during tilt measurement, ExtremeRTK receiver tilt measurement solution adopts a new design, choosing the latest generation of IMU firmware, equipped with ExtremeRTK™ technology. After the initial initialization is completed, in conventional measurement scenarios such as detailed point acquisition, due to the movement makes IMU continuously obtain attitude compensation information, ExtremeRTK receiver can achieve no failure during the whole measurement. ExtremeRTK receiver can achieve the whole measurement without failure. To present the ExtremeRTK receiver tilt performance, the tilt valid time at rest was measured at a fixed point and at a specific tilt angle. The test was conducted in an open sky environment with a 5km test baseline, and the measured tilt angles were 10°, 30°, 45°, and 60°, and the tilt state hold time was counted for each angle. As shown in Table 2, **even at a tilt angle of 60°, the tilt valid time can still last 216s (about 4 minutes)**. Compared with the performance of **the competitor manufacturers in the market that tilt valid time only lasts 30s**, ExtremeRTK receiver has significantly improved the tilt measurement availability.

Table 2 Tilt valid time for different angle

Tilt angle (°) / Hold time (s)	10°	30°	45°	60°
Time	＞600	510	442	216

Tilt measurement accuracy in open sky

Tersus has established an independent board research and development strategy from the very beginning, which enables us to control the whole process of GNSS positioning solution. The self-researched BX40C board based on ExtremeRTK^{TM} technology supports all-constellations multi-frequency, with the ability to search up to 50+ satellites, ensuring the correctness of the solution results.

In order to demonstrate the accuracy of tilt measurement, this test was conducted in an open sky environment with a 5km test baseline, and the measured tilt angles were 10°, 30°, 45° and 60°, and the accuracy of continuous tilt measurement under each angle was counted. In tilt valid state, measure continuously at 1s interval and calculate the mean square error in plane and elevation. Figure 16 shows that at 10° tilt angle, for 600 observations the plane mean square error is only 1.02cm and elevation mean square error is only 0.83cm; Figure 17 shows that at 30° tilt angle, for 510 observations the plane mean square error is only 1.59cm and elevation mean square error is only 0.54cm; Figure 18 shows that at 45° tilt angle, for 442 observations the plane mean square error is only 0.95cm and elevation mean square error is only 0.57cm; Figure 19 shows that at 60° tilt angle, for 216 observations the plane mean square error is only 0.95cm and elevation mean square error is only 0.57cm; Figure 20 shows that at various tilt angle, for 1768 observations the plane mean square error is only 1.96cm and elevation mean square error is only 0.77cm. **It can be seen that even under the tilt angle of 60°, the mean square error of tilt measurement can still be controlled within 2cm.**

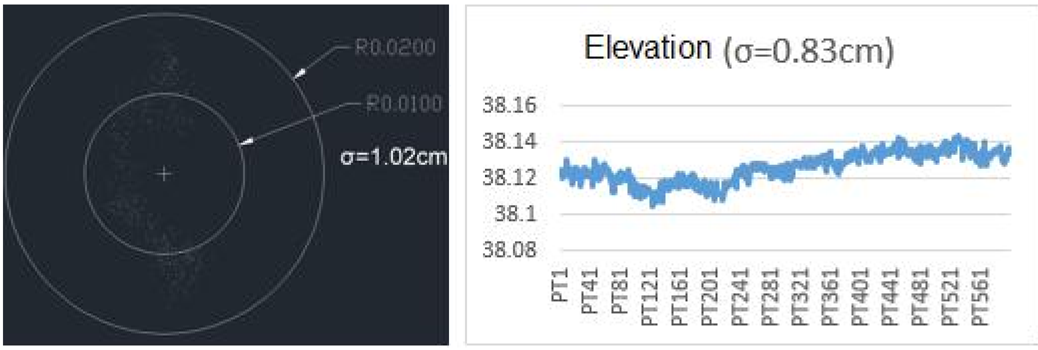

Figure 16 RMS of plane and elevation error in 10° tilt angle

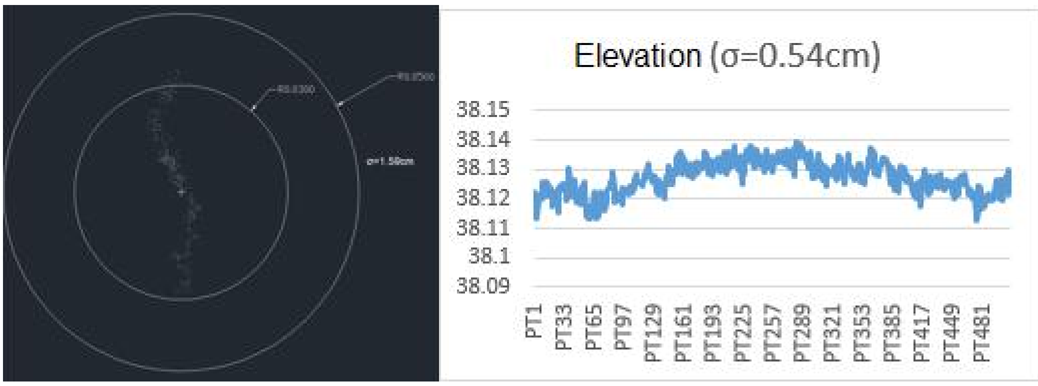

Figure 17 RMS of plane and elevation error in 30° tilt angle

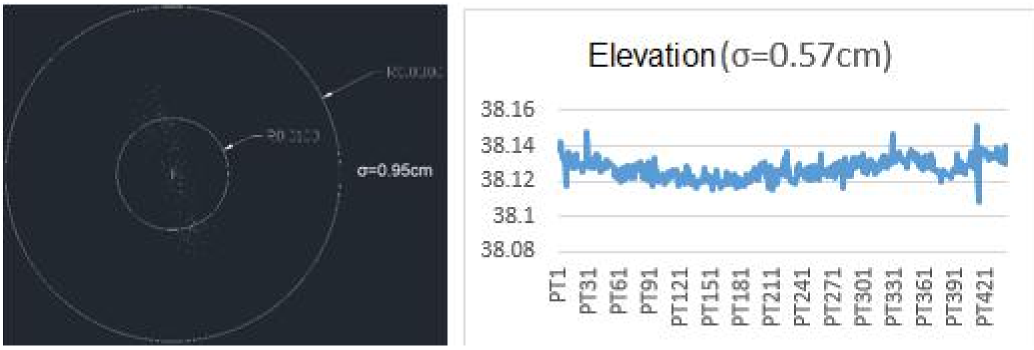

Figure 18 RMS of plane and elevation error in 45° tilt angle

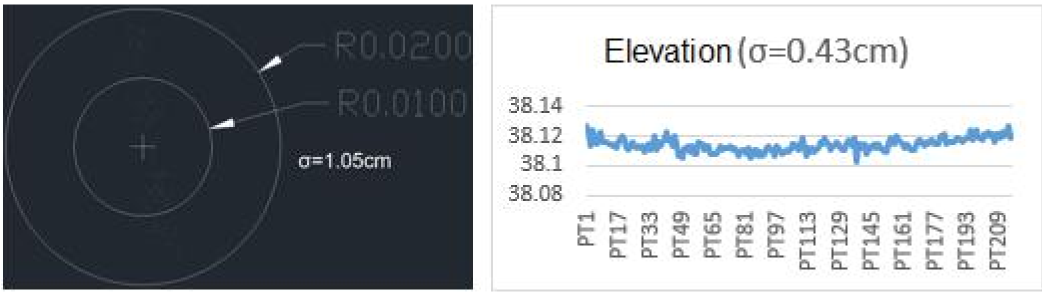

Figure 19 RMS of plane and elevation error in 60° tilt angle

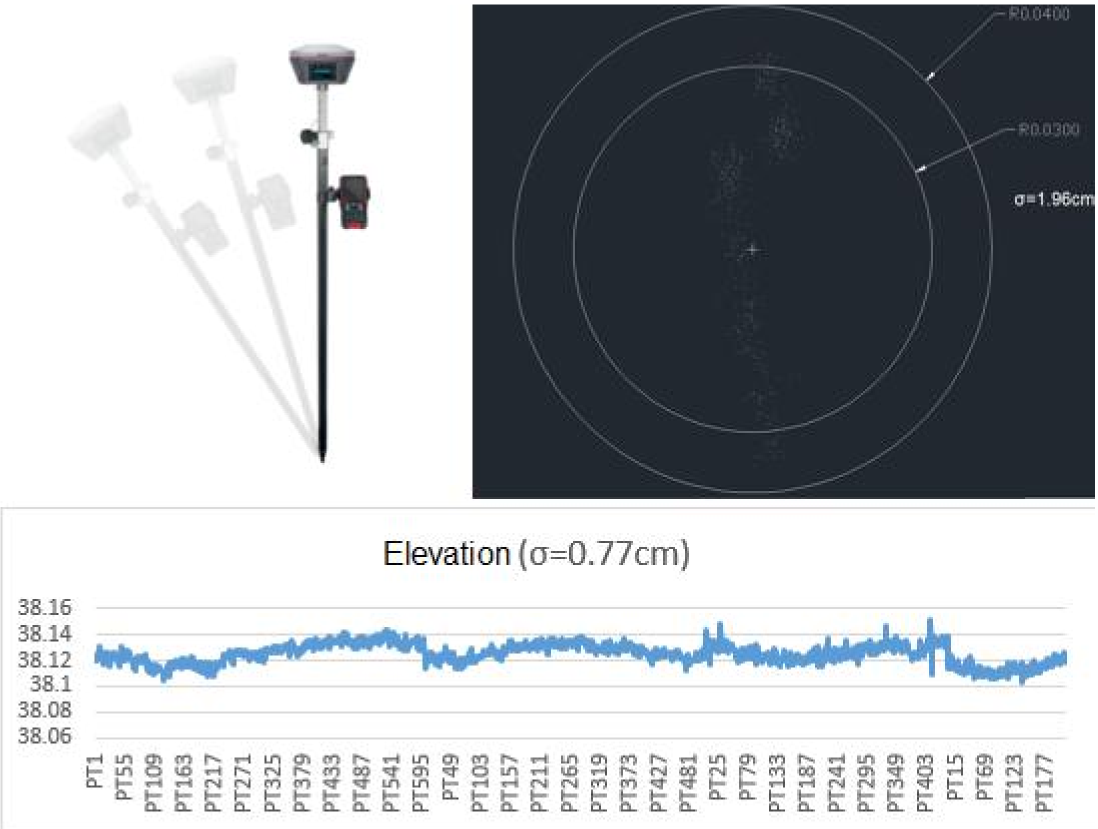

Figure 20 RMS of plane and elevation error in various tilt angle

Tilt measurement accuracy in extreme obscured environment

In order to present the excellent performance of the tilt measurement scheme, the half-sky occlusion and urban canyon environment were selected to carry out the statistics of tilt measurement accuracy under the extreme obscured environment. The base station uses domestic commonly used Qianxun account, with 1s acquisition interval, 600 points are continuously collected in each scenario, and then perform statistical analysis of plane and elevation RMS. Figure 21 shows that in the half-sky obscured environment, for 604 points it has a mean square error of 1.35cm in plane and 1.59cm in elevation; Figure 19 shows that in the urban canyon obscured environment, for 611 points it has a mean square error of 1.31cm in plane and 1.51cm in elevation. **It can be seen that the tilt measurement can still maintain high accuracy observation even in the extreme obscured environment.**

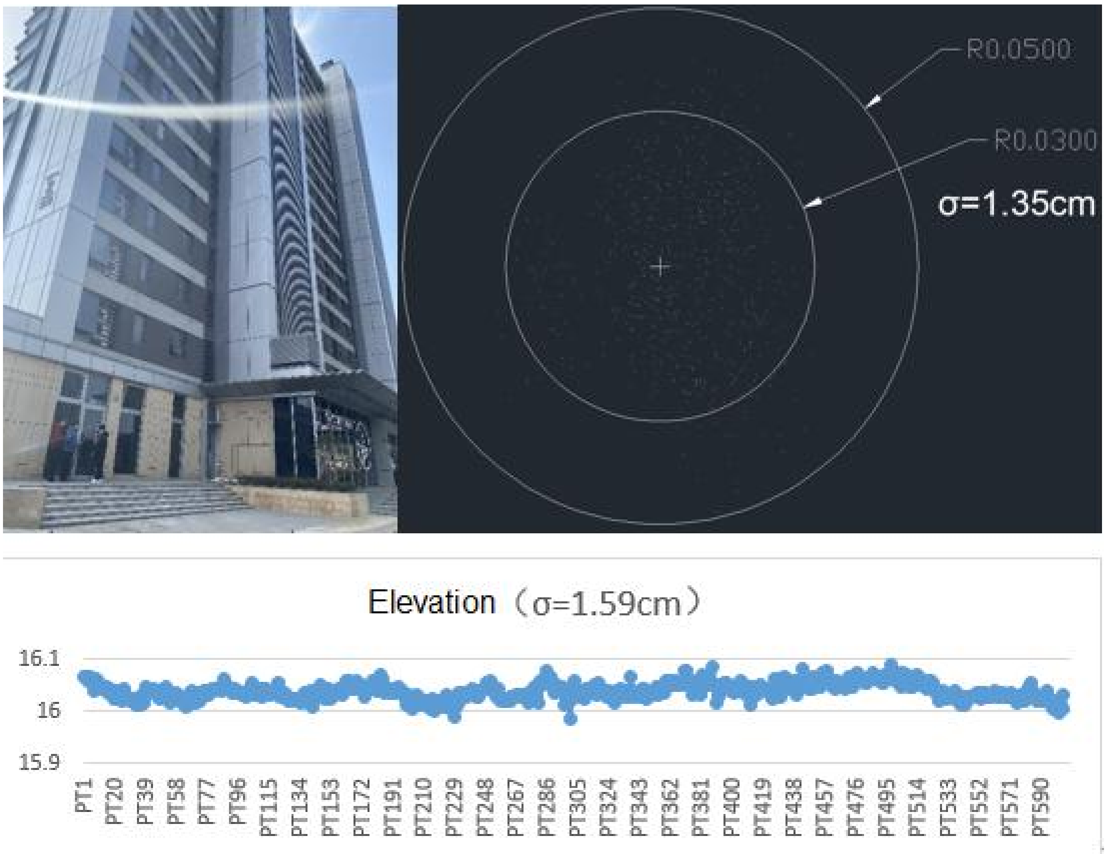

Figure 21 Error RMS for tilt measurement in half-sky obscured environment

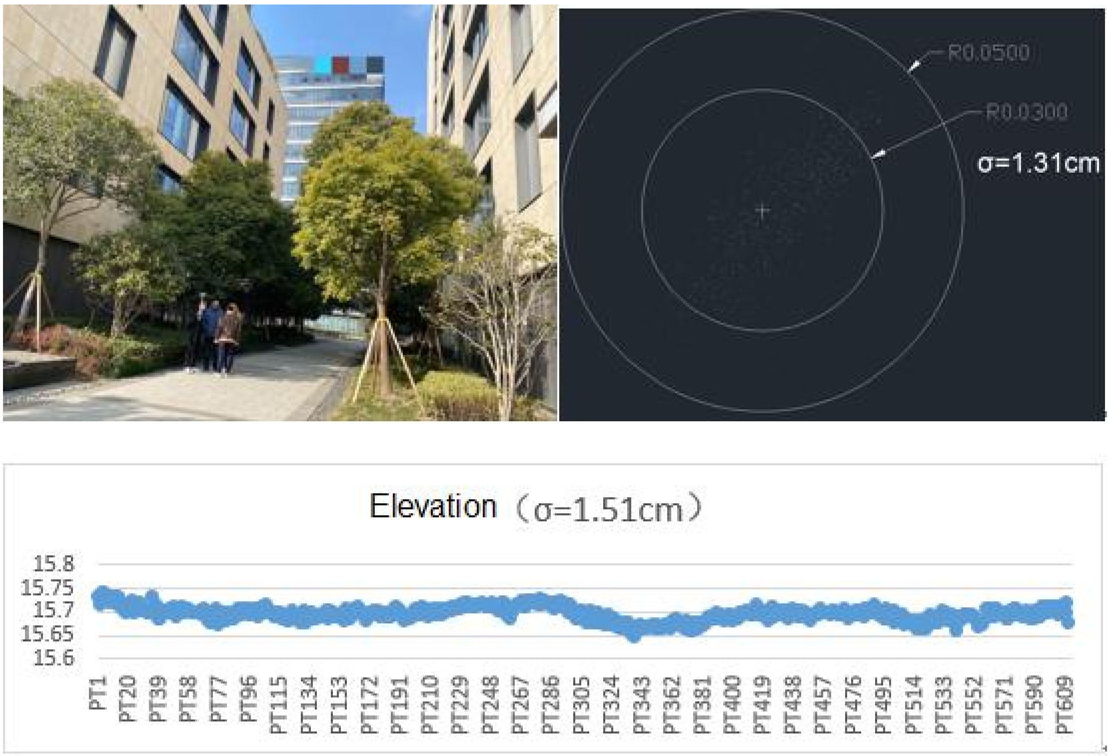

Figure 22 Error RMS for tilt measurement in urban canyon

Conclusions

The relevant test results have been presented in this white paper, indicating that ExtremeRTK™ has remarkable performance in terms of board initialization speed, accuracy persistence, tilt measurement, etc., and it has the strength equivalent to international mainstream brands. We will continue to invest in hardware devices such as ExtremeRTK series receivers, photogrammetry, laser scanning, etc., on the basis of ExtremeRTK™; meanwhile, we will focus on professional industry software development, integrate resources in data management and big data application, and provide users services such as global CORS raw data download, VRS service, precision ephemeris download, high precision ionosphere/troposphere model, fast PPP and other professional services to create a new Tersus ecological platform and bring more possibilities and convenience for user applications.

Tersus will always adhere to the original intention of 'walk step by step to reach ambitious goals' and continue to contribute Tersus's wisdom and strength to promote the progress of GNSS.