

# Tersus ExtremeRTK™

## Technology White Paper

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# Preface

With the increase of navigation satellite constellations, and associated signals, scenarios for RTK (real-time kinematics) use have greatly expanded. Meanwhile, occurrences of false ambiguity resolutions and RTK Positioning outliers in challenging environments continue to pose quality risks for surveying and mapping. The occurrence of false ambiguity resolution and occasional RTK positioning outliers is partially caused by the excessive pursuit of rapid RTK fix and high fix rates. It can be difficult for surveyors to identify errors on site easily and quickly. Therefore, a stable, reliable, and accurate RTK product, applicable for all scenarios should be a primary goal for all manufacturers of survey-grade GNSS systems. If we take a look at the latest RTK receivers from some leading manufacturers, the emphasis is still on the stability and accuracy of RTK for various scenarios and applications.

As a professional RTK developer and manufacturer, Tersus is customer-oriented and aims to provide the most reliable products. Its industry-leading RTK products ensure accuracy as well as preventing false ambiguity resolution and occasional RTK positioning outliers. This white paper will focus on the technical aspects of Tersus's ExtremeRTK™ technology, that delivers excellent performance in all manner of scenarios.

In the high-precision IoT (Internet of Things) field, more and more devices are integrating high precision positioning. For example: agricultural tractors, shared bikes and scooters, unmanned lawn mowers, precision-controlled drones, and unmanned delivery trucks. These all have embedded GNSS modules, and may

also include other integrated sensors, like IMU (inertial measurement unit). The coordination of a high-precision RTK positioning and inertial navigation systems has become an important topic. Tersus has developed core algorithms for the integration of high-precision modules, and has produced its first receiver with calibration-free tilt compensation through the coordination of RTK and IMU. Tersus GNSS systems with this capability have seen a rapid rise in popularity among users all over the world. We will continue to develop more quality products incorporating integrated RTK and IMU technologies. This white paper will also demonstrate the features and advantages of the Tersus tilt compensation approach.

Recognizing the complexities of a RTK products for surveying, we chose as our development approach, to start from scratch—engineering each element from its foundation in the physics of GNSS. From signal capture and baseband tracking engine to PVT (position-velocity-time) results and the overall algorithm of RTK, Tersus completes all algorithm logic independently. The independent R&D by Tersus stands in contrast to many RTK manufacturers that simply buy OEM (original equipment manufacturer) components from a handful of manufacturers. Independence is a core value for Tersus: to compete with the few, fully independent manufacturers worldwide.

ExtremeRTK™ emerged from this background and as a patented technology from its inception. Tersus will continue to develop its markets for surveying and high-precision navigation, continually providing customers with more options.

# 1. Abstract

This white paper discusses Tersus's latest ExtremeRTK™ technology. ExtremeRTK™ integrates the receiver's hardware, high precision baseband IC, RTK engine, GNSS/INS coupling algorithm, etc. It enables unprecedented performance stability in challenging environments and prevents occurrences of occasional RTK positioning outliers. The ExtremeRTK™ solution includes:

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## **Self-developed GNSS high-precision baseband IC tracking algorithm**

with strong resistance to pseudorange and carrier phase multipath and strong mitigation of reflected multipath from buildings/water/ground and scattered multipath under trees.

## **The RTK algorithm performs a comprehensive check on the ambiguity search results in multiple dimensions**

including aperture, residual, and global time domain, etc. , to ensure that each group of accepted ambiguities has high credibility.

## **RTK does a comprehensive comparison of each accepted set of ambiguities, compared with a large number of other ambiguities (several hundred sets)**

to ensure that each accepted ambiguity set is optimal in a large enough space.

## **The test department has a database of thousands of test cases in various challenging environments and this database continues to grow**

Before each version is updated and iterated, the case library test must be passed as a precondition for release.

## **The innovative GNSS/INS coupling algorithm and accuracy control mechanism**

ensures that the tilt compensated results meet expectations.

## **The GNSS boards are capable of recording raw observation data**

including raw RTCM data and baseband trace output results.

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

All data in this paper comes from the Tersus R&D team, and this paper further elaborates on the four most important factors of GNSS for surveying:

- Signal tracking capability
- Fix speed
- Precision and accuracy
- Operational efficiency

The base stations used in the tests include Tersus and other mainstream manufacturers' CORS (continuously operating reference station) services. The Oscar Ultimate receiver has been tested in different environments, to include of open sky, limited sky-view, dense tree canopy, urban canyons, etc. Pictures of the various test environments have been included in the subsequent test projects presented in this paper.

The main content of this paper is outlined as follows:

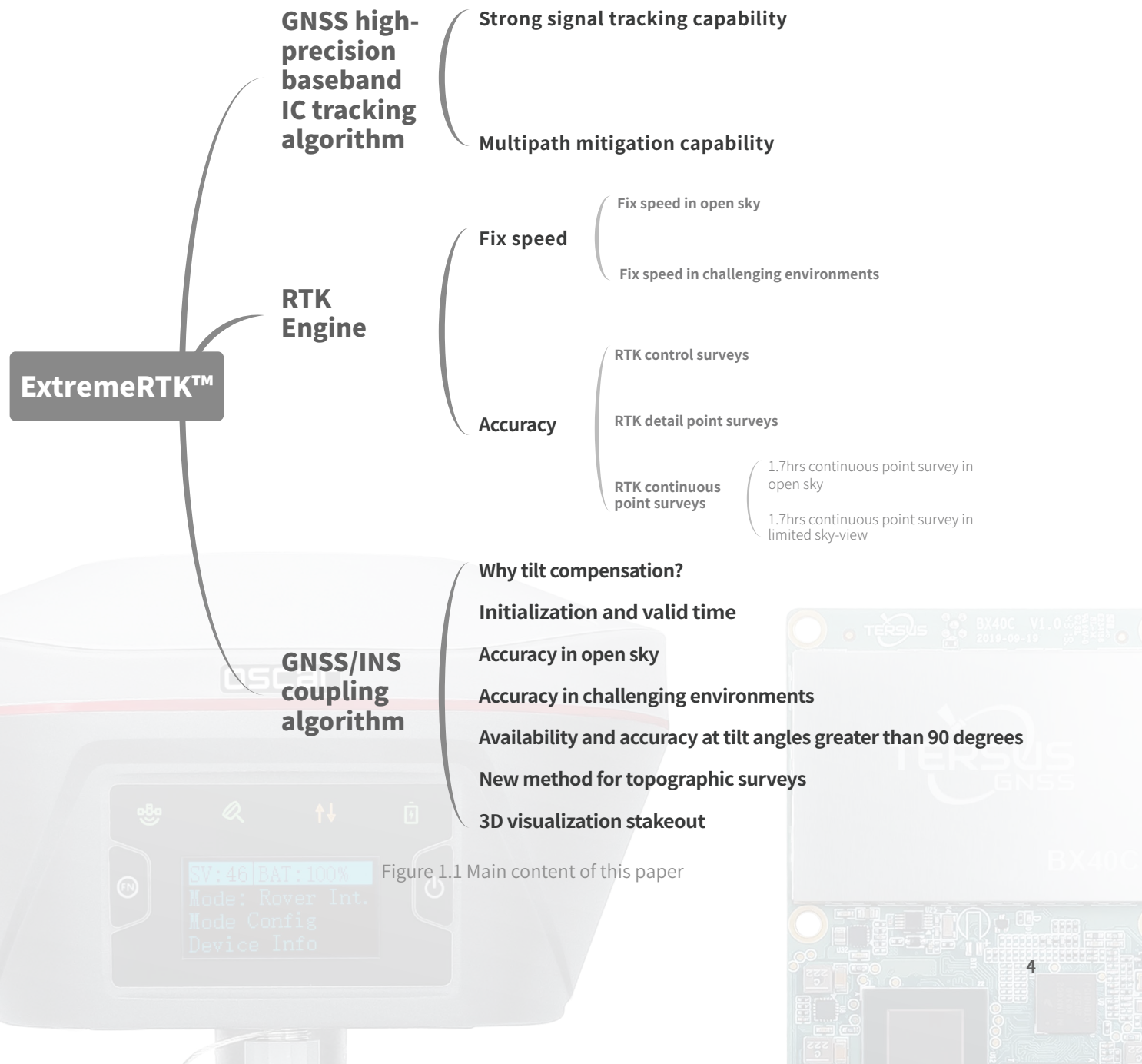


Figure 1.1 Main content of this paper

## 2. Signal tracking and multipath mitigation capabilities

### 2.1 Strong signal tracking capability

With ExtremeRTK™ technology, Oscar GNSS receivers can **simultaneously track the satellite signals of sixteen frequencies in the five constellations of BDS-2/BDS-3, GPS, GLONASS, Galileo, and QZSS, easily achieving 50+ satellites tracked on the ground.** The continuous optimization of GNSS high-precision baseband IC (integrated circuit) and RTK algorithm enables Oscar to not only search more satellites, but also effectively filter

out signals with serious multipath error and low signal-to-noise ratios. In urban canyons and dense tree canopy areas, where conventional receivers cannot measure due to insufficient search capabilities or large noise, Oscar can still achieve high-precision. Being able to perform in all sky-view-scenarios, weather, and various multipath profile environments, Oscar has greatly broadened the application of RTK for surveying.

Constellation	Frequencies
BeiDou	B1I, B2I, B2a, B3I
GPS	L1 C/A, L2C, L2P, L5
GLONASS	L1 C/A, L2 C/A
Galileo	E1, E5a, E5b
QZSS	L1 C/A, L2C, L5

Table 2.1 Oscar's satellite tracking capability

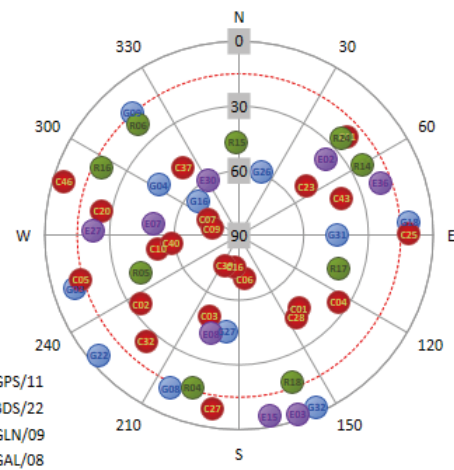


Figure 2.1 Sky map of satellite tracking

### 2.2 Multipath mitigation capability

According to the RTK double-difference model,

$$\Delta\varphi_{AB}^{jk} = \frac{f}{c} \Delta\rho_{AB}^{jk} - \Delta N_{AB}^{jk} - \frac{f}{c} (V_{ion})_{AB}^{jk} - \frac{f}{c} (V_{trop})_{AB}^{jk}$$

where  $\Delta\varphi$  is the carrier phase observation,  $\Delta\rho$  is the pseudorange observation,  $\Delta N$  is the whole circumferential ambiguity,  $V_{ion}$  is the ionospheric delay,  $V_{trop}$  is the tropospheric delay. Through the double-difference solution, satellite clock error and

receiver clock error are completely eliminated. Considering the proximity of two stations, the error caused by ionospheric and tropospheric delay will be eliminated according to the ionospheric and tropospheric spatial correlation. Thus, the greatest source of RTK positioning error is often multipath.

ExtremeRTK™ creatively adopts a new solution that significantly mitigates multipath effects through

hardware design, such as the anti-multipath antenna, and GNSS high-precision baseband IC algorithms. The zero-baseline testing method employed introduces the same observation signal to receiver brand A, Tersus BX40C, receiver brand B and receiver brand C (herein referred to as REC1, REC2 (BX40C), REC3, and REC4). Figure 2.2 and 2.3 provide their respective pseudorange multipath statistics. The abscissa represents GNSS satellite frequencies, and the ordinate represents multipath error. The smaller the error, the better the

performance. Figure 2.4 to 2.6 shows the comparison of carrier multipath mitigation effects, in which the sky map corresponds to different satellite elevations for GPS, GLONASS, Galileo and BeiDou constellations. The lighter the color (green), the better the performance. It can be seen that **BX40C has stronger capability for mitigating multipath error at each frequency, especially for the BeiDou constellation and low-elevation satellites.**

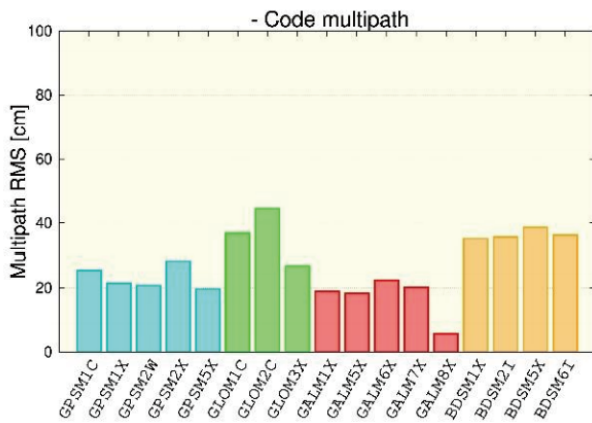


Figure 2.2 Pseudorange multipath statistics of REC1 and REC2 (BX40C)

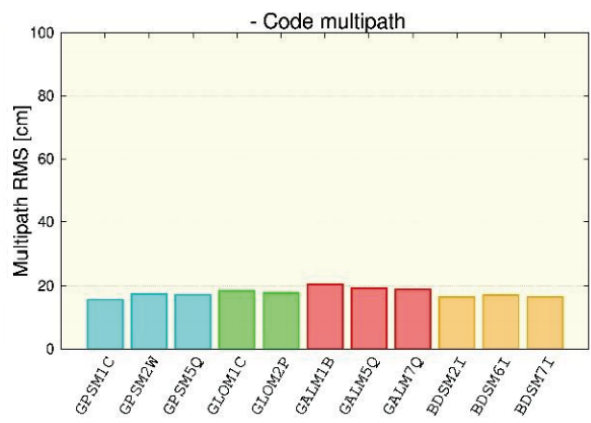


Figure 2.3 Pseudorange multipath statistics of REC3 and REC4

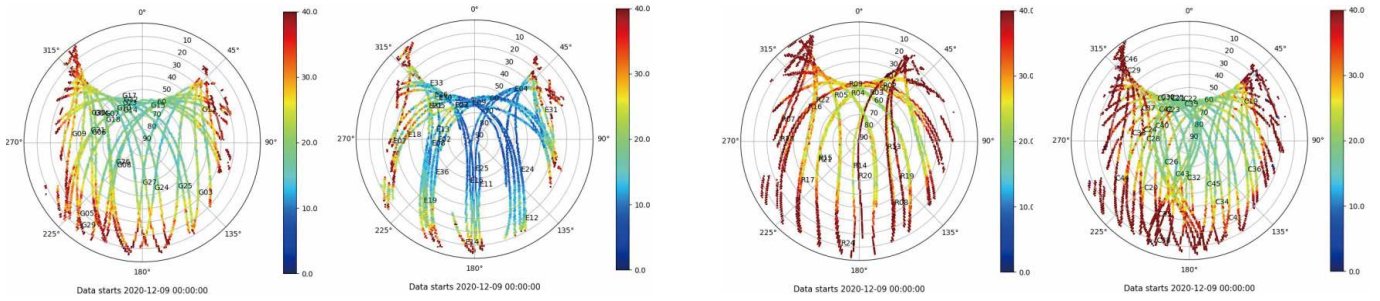


Figure 2.4 Sky map- carrier multipath error of REC1

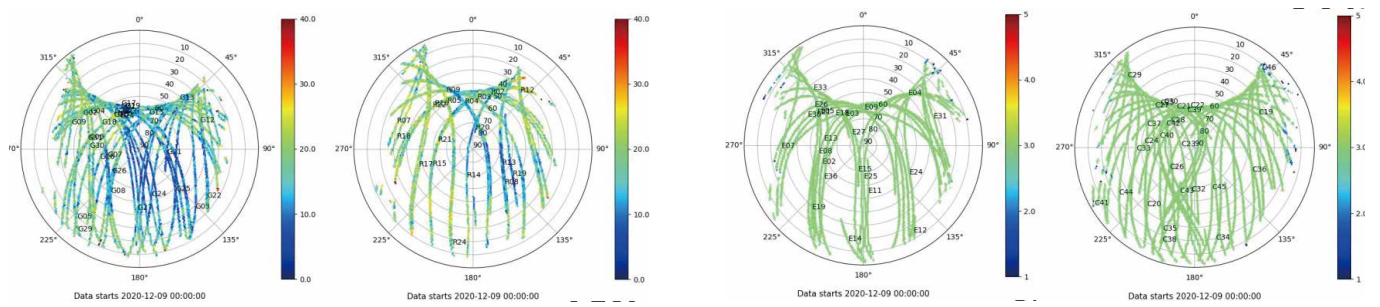


Figure 2.5 Sky map- carrier multipath error of REC2 (BX40C)

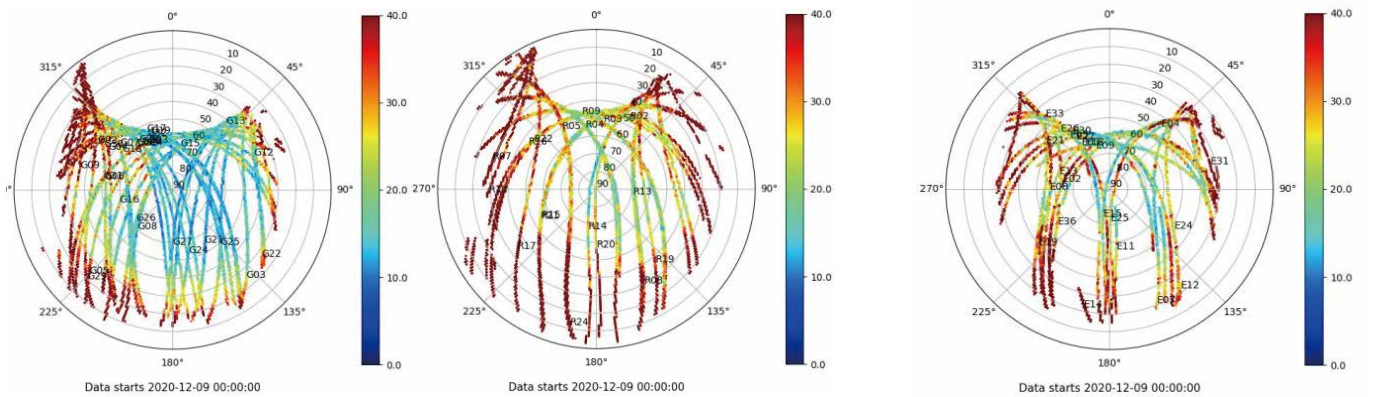


Figure 2.6 Sky map- carrier multipath error of REC3

## 3. ExtremeRTK™ fix speed

### 3.1 ExtremeRTK™ fix speed in open sky

To present ExtremeRTK™ fix speed accurately, our test adopts a Tersus base station, with a baseline distance of 15km, and an open sky environment. We use the state identifier in the GPGL data stream and count the duration from receiving the first packet of correction data to a fixed RTK state, as TTFF (time to first fix). A total of 59 RTK resets were done; each RTK reset is a full

re-initialization (ambiguity resolution). The BX40C TTFF is shown in figure 3.1. It can be seen that **in open sky, 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 through ExtremeRTK™ technology.**

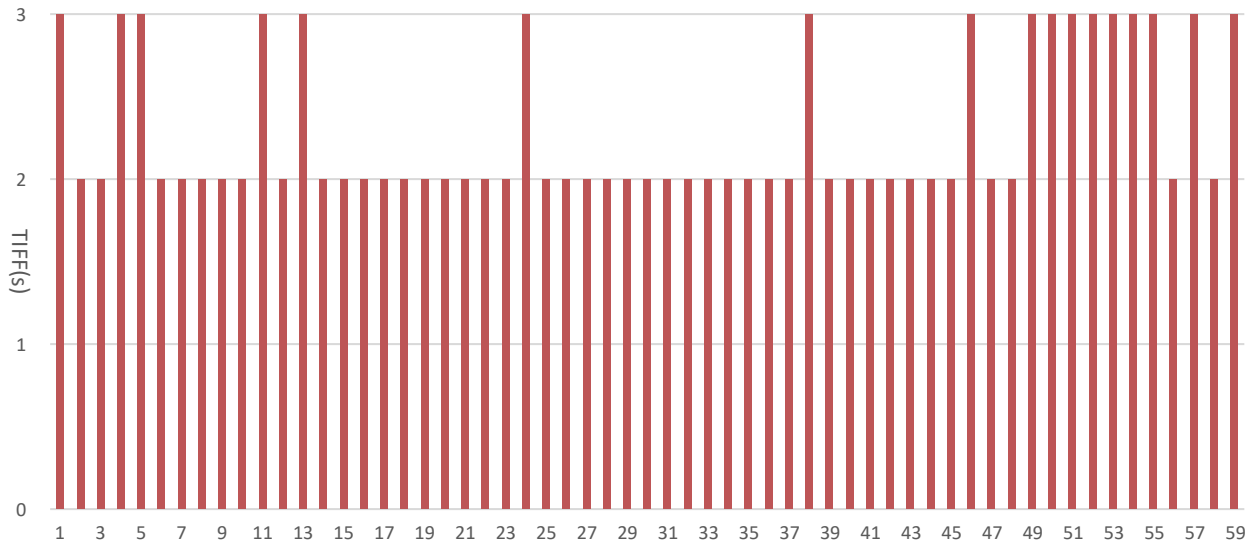


Figure 3.1 TTFF at 15km baseline

### 3.2 ExtremeRTK™ fix speed in challenging environments

To further demonstrate the excellent performance of ExtremeRTK™, the challenging scenario of Figure 3.2 was selected to test the fix speed. This scenario has multipath reflection error caused by glass and hard walls as well as scattering multipath error caused by dense tree canopy. Similar to the open sky scenario, we conduct the RTK reset 23 times to determine the RTK fix speed performance. After each reset, one

measurement is conducted at the reference point. In this test, **the shortest RTK fixed time is 11 seconds, the longest time is 29 seconds, and the average is 17.9 seconds; the measured value is 3.5cm of maximum error and 0.8cm of minimum error from the true value (3D Error), fully meets the measurement specification.**



Figure 3.2 Outlook of challenging environment

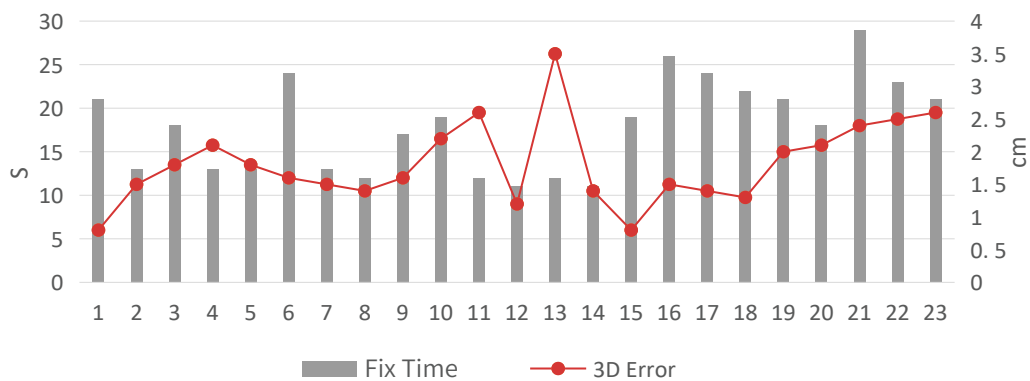


Figure 3.3 RTK fix time

## 4. ExtremeRTK™ accuracy

### 4.1 RTK control surveys

With the maturity of RTK, many countries/cities have now approved its use for control surveys. Taking DG/TJ08-2121-2013 "Shanghai Engineering Construction Specification- Technical Specification for Satellite Positioning Measurement" as an example, the specification stipulates that RTK horizontal control surveys should be carried out only after an RTK fix, and for each measured point, RTK should be independently

initialized twice. Two sets of data should be collected for each initialization; the horizontal difference of four sets of data should be less than 2cm. Repeated sampling checks should be carried out on the next day or near the time of the completion of the field collection, and the difference between repeated sampling checks and the initial collection should be less than 3cm.

The specification further stipulates that RTK geodetic height control surveys should be carried out after an RTK fix, and each point measured, RTK should be initialized four times independently. Two sets of data should be collected for each initialization, and the vertical difference between the eight sets of data of each point should be less than 3cm. Repeated sampling checks should be carried out on the next day or near the time of the completion of the field collection, and the point vertical difference between the repeated sampling checks and the initial collection should be less than 5cm.

With reference to the Shanghai GNSS Control Survey Specification, we adopted a Tersus 5km baseline and

designed a test of four periods over a total of 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 period, the receiver was initialized eight times, and two sets of data were collected after each initialization. Thus, 16 sets of data are collected in a single period and 66 sets of data are collected in total. From the table below, we can see that, **under a more stringent surveying environment than required, the difference during the single period and the error RMS (Root Mean Square) in each period both meet the requirements of the Shanghai specification.**

	Points	Horizontal error (RMS)	Vertical error (RMS)	Maximum difference (Horizontal)	Maximum difference (Vertical)	Spec requires (Horizontal)	Spec requires (Vertical)	Meet the spec.
Period 1	16	0.32cm	0.42cm	0.83cm	1.32cm	≤2	≤3	Yes
Period 2	16	0.25cm	0.39cm	0.79cm	1.32cm	≤2	≤3	Yes
Period 3	18	0.35cm	0.78cm	1.24cm	2.68cm	≤2	≤3	Yes
Period 4	16	0.29cm	0.96cm	0.85cm	2.66cm	≤2	≤3	Yes
Difference	66	0.66cm	0.74cm	2.66cm	3.66cm	≤3	≤5	Yes

Table 4.1 Statistics of RTK control survey

## 4.2 RTK detail point surveys

To test accuracy for detail point surveys (e.g. topographic), we set the control points in a challenging environment and determined the true value accurately by conducting a total station traverse. In each of the four periods of 2021-03-22 12:25, 2021-03-22 13:42, 2021-03-22 14:52, and 2021-03-22 16:08, the receiver was switched on and off independently. One group of data was collected respectively in each cardinal direction

(east/west/south/north). Thus, four groups were collected in each period and 16 groups are collected in total. **According to statistical analysis, the maximum value of 3D error was 4.0cm and the minimum value was 0.6cm. The percentage of points with a 3D error less than 3cm was more than 81%. The 3D error RMS was 2.35cm, which met the requirement of detail point surveys.**



Figure 4.1 RTK detail point survey in challenging environment

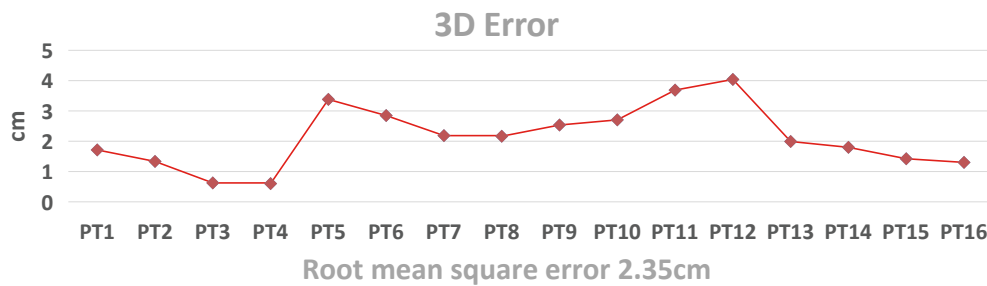


Figure 4.2 3D error analysis of RTK detail point survey in challenging environment

### 4.3 RTK continuous point surveys

To demonstrate the stability and accuracy of ExtremeRTK™ for continuous point (kinematic) surveys, tests were conducted in two environments: open sky and limited sky-view. In each environment, 1,200 points were observed continuously over a 1.7-hour periods. Then we calculated the horizontal and vertical error RMS value. **As shown in Figure 4.3, in open sky, the horizontal error of 1,200**

**points in 1.7 hours is only 0.64cm and the vertical error is only 1.44cm. As shown in Figure 4.4, in the challenging limited sky-view environment, with 10-story building and dense tree canopy, the horizontal error of 1,200 points in 1.7 hours is only 2.40cm and the vertical error is only 3.08cm.** Thus it is a verification that ExtremeRTK™ is fully qualified for all scenarios.

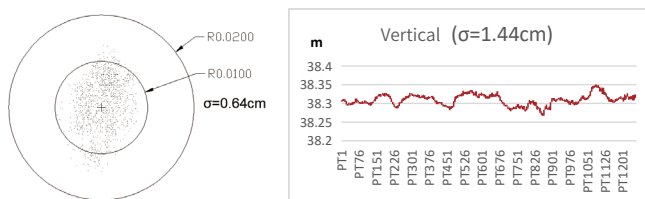


Figure 4.3 Continuous RMS in open sky

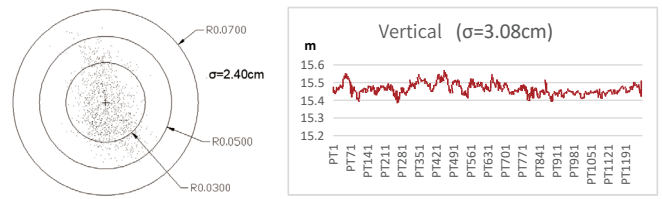


Figure 4.4 Continuous RMS in limited sky-view

# 5. GNSS/INS tilt compensation

## 5.1 Why tilt compensation?

With GNSS technology, the coordinates obtained directly are not that of the target point of the pole tip but of the phase center of the receiver antenna. Therefore, with traditional RTK, the phase center coordinates can be calculated relative to the pole tip only when the pole is strictly upright, and the pole height is known. The pole must remain completely vertical throughout the measurements, with the help of the bubble indicator. This legacy method can be the cause of the problems listed below:

- a. Certain hidden points cannot be measured in the traditional way (such as points under a car);**
- b. It can be dangerous to do measurements in certain places, like in roadways and at the edge of cliffs.**

It can be inefficient, and accuracy can be greatly affected by lapses in diligence by surveyors. For inexperienced surveyors, it can be difficult and physically demanding to ensure the bubble remains centered throughout the entire process. GNSS and IMU based tilt compensation technology changes and improves the process.

While the coordinates directly from GNSS are still of the receiver antenna phase center, through the six-axis IMU output and GNSS/INS coupling algorithms, the Oscar GNSS Receiver can output the attitude information of the receiver and pole. With pole height as an input, a quick realization of a series of transformations of body-fixed

coordinate systems- NED (north-east-down) coordinate systems- ECEF (earth-centered-earth-fixed) coordinate systems can be performed. Together with a real time calculation of the receiver phase center coordinates relative to the pole tip, the target position can be achieved. The user only needs to turn on the receiver and input the pole height correctly, then subsequent measurements can be carried out at any pole tilt angle.

- The advantages of Tersus's tilt compensated survey solution can be summarized as:
- a. For signals at low elevation angles, an advantage of the BX40C baseband IC algorithm is that it can effectively mitigate observation errors such as multipath;**
  - b. Equipped with the cutting edge IMU hardware, abandoning the traditional solution based on the magnetometer for heading, it is not affected by geomagnetism or surrounding magnetic objects;**
  - c. Supporting larger tilt angles. Larger tilt angles can help keep the antenna away from obstructions, which widens the satellite searching field and weakens the influence of multipath effects, enabling measurements in more surveying scenarios;**
  - d. Reliable GNSS and IMU coupling algorithms, provide an efficient accuracy control mechanism to ensure that the output meets expectations.**



Figure 5.1 Tilt survey- on the high way

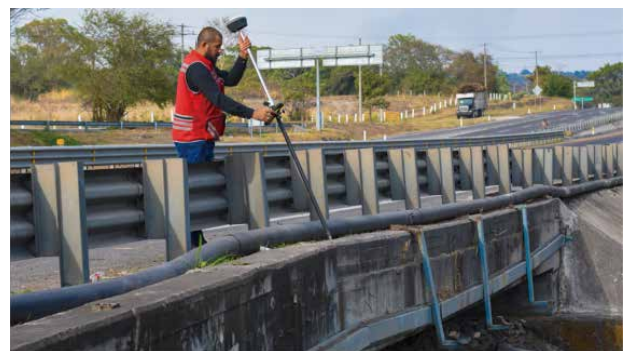


Figure 5.2 Tilt survey- on the bridge

## 5.2 Initialization and valid time

As identified through extensive market research, initialization time, and time to achieve and maintain valid tilt compensation, is one of the most important user concerns. Looking back at the development of tilt compensation solutions, the first-generation solutions have been gradually abandoned because the design is based on magnetometers for heading, which can be seriously affected by the surrounding geomagnetic environment. Magnetometer-based tilt systems also required frequent and cumbersome calibration steps, and the efficacy of the calibration could change during a work day due to local sources of magnetism. The ExtremeRTK™ receiver, benefits from the latest high-performance, high-precision, six-axis IMU, and therefore is completely immune to magnetic interference.

It is ready to survey once the surveyor turns on the receiver and walks to the first point of interest—the integrated GNSS/IMU solution self-calibrates rapidly during this first induced movement. According to our tests, compared with the 40s' initialization time of the flagship receiver of the mainstream brand A, Tersus Oscar Receiver with ExtremeRTK™ technology needs only 5-15s random movement for initialization, which is obviously faster and easier. For details, please refer to this test video: <https://youtu.be/Pr5eFV8WNtc>.

Meanwhile, in order to solve the problem of easy loss of a valid tilt compensation state, the ExtremeRTK™ tilt compensated survey solution incorporates a newly designed innovative GNSS/IMU coupling mechanism. It enables the user to initialize the tilt compensation even when the receiver is in a status of single point positioning. This differs from the tilt compensation approaches of some other brands that need to ensure the receiver's RTK status is fixed. In the Tersus solution, the IMU does not need to be reinitialized even after Tersus Oscar Receiver loses its fixed RTK solution.

To demonstrate the ExtremeRTK™ receiver's tilt performance, the test was conducted in an open sky environment with a 5km baseline and tilt angles of 10°, 30°, 45°, and 60°. The holding time of the tilt compensation available state was counted for each angle when Tersus Oscar Receiver was still. As shown in table below, even at 60°, the tilt available time can still last 216s (about 4 minutes). Compared with the performance of the other manufacturers, of which the tilt available time lasts only 30s, the ExtremeRTK™ receiver has significantly improved the tilt compensation availability.

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

Table 5.1 Tilt available time for different angle

## 5.3 Accuracy in open sky

To demonstrate the tilt compensation accuracy, measurement was conducted at tilt angles of 30°, 45° and 60° on a control point on the roof of Tersus's main building where R&D is conducted. The accuracy at each angle was counted. The test procedure steps were as follows:

1. Firstly, turn off the tilt compensation function, level the

pole, face the Tersus Oscar Receiver to 8 directions and measure 8 times. Take the average value as the true value for this control point. Then turn on the tilt compensation function, with the tilt direction starting from the north, tilt the pole 30° and measure this control point once and set the measurement epoch for 5s.

2. Adjust the tilt direction of the pole clockwise at 45° intervals, tilt the pole 30° to measure the control point, and set the measurement epoch for 5s.
3. Repeat step 2 until all 8 tilt directions of data is collected. 12 cycles equate to 96 sets of data collect in total.

4. After the data collection of 30° tilt angle, repeat steps 1-3 to collect data of 45° and 60° tilt angles.

**The 3D error analysis of the statistics shows that even at the large tilt angle of 60°, the error RMS of the 94 sets of data is only 1.99cm.**

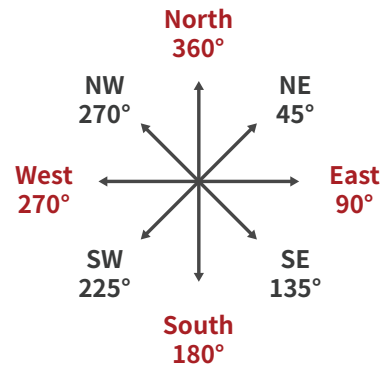


Figure 5.3 Test location and eight directions

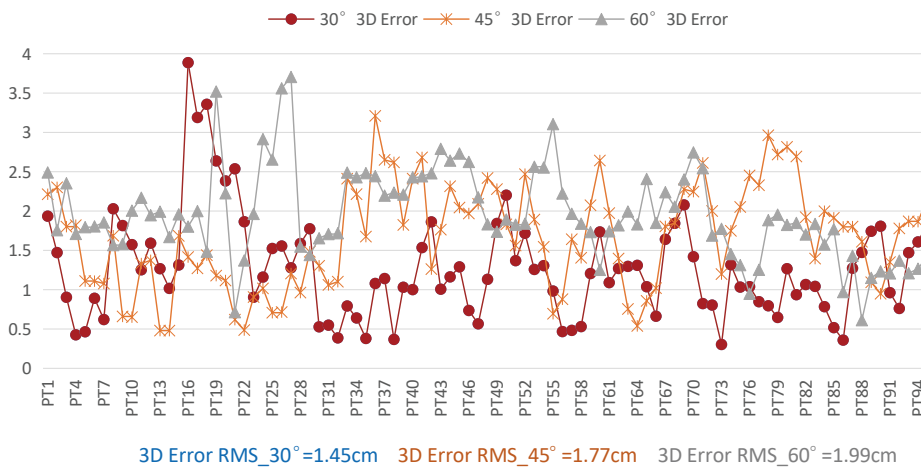


Figure 5.4 3D error analysis at three tilt angles in open sky

Given the excellent performance of Tersus Oscar GNSS Receiver with ExtremeRTK™ tilt compensation, surveying is no longer affected by the magnetic disturbance and tilt angle. Even at the large angle of 60°, it can still provide high accuracy RTK solutions with the empowerment of robust capabilities in tracking satellite signals. Therefore, ExtremeRTK™ is more suitable for the measurement of

concealed points, like house corners and points that are dangerous to access. The images below show that for points in manholes and under cars, **even with a tilt angle of 50~60°, the RMS can still be stable within 2cm.** Note that due to the limitation of measuring methods, the average value of each angle is taken as the most reliable value, and assume it as true value.



Figure 5.5 Tilt survey for a manhole

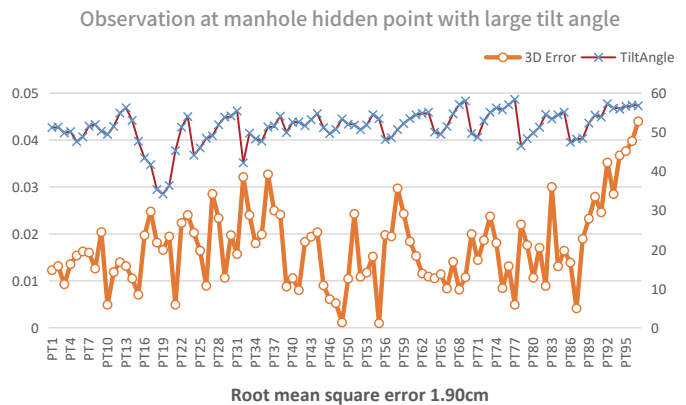


Figure 5.6 3D error at manhole hidden point with large tilt angle

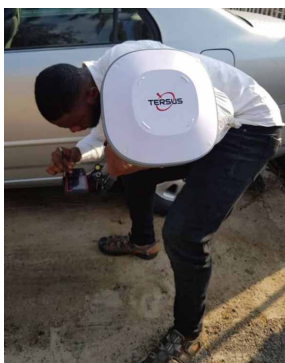


Figure 5.7 Tilt survey under a car

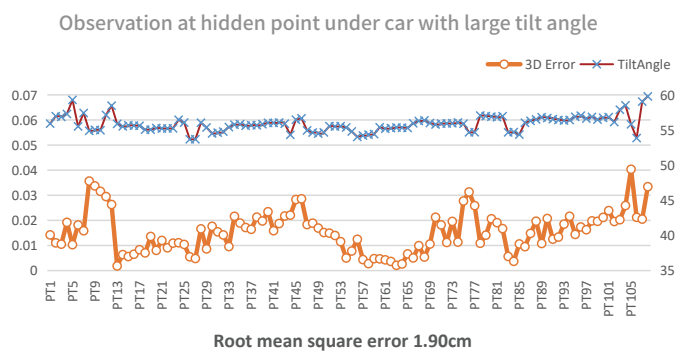


Figure 5.8 3D error at hidden point under car with large tilt angle

## 5.4 Accuracy in challenging environments

To demonstrate the excellent performance of tilt compensation, the example challenging environments of limited sky-view and urban canyons were selected for testing. 600 points are collected continuously in each environment at a 1s (1 Hz) acquisition interval. The horizontal and vertical error was calculated, using the average of all measurements as the most probable true value. Figure 5.10 and Figure 5.11 show that for 604 points

collected in the challenging limited sky-view environment, there was a root mean square error of 1.35cm horizontally and 1.59cm vertically. Figure 5.13 and Figure 5.14 show that for 611 points collected in the urban canyon environment, there was a root mean square error of 1.31cm horizontally and 1.51cm vertically. It can be seen that the tilt compensation can still maintain high accuracy even in challenging environments.



Figure 5.9 Limited Sky-view environment

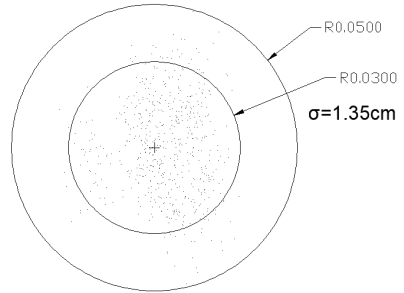


Figure 5.10 Horizontal error in limited sky-view environment

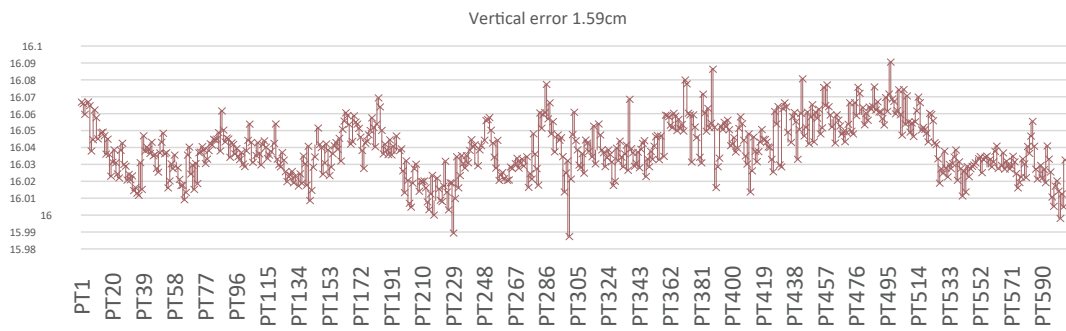


Figure 5.11 Vertical error in limited sky-view environment



Figure 5.12 Urban canyon environment

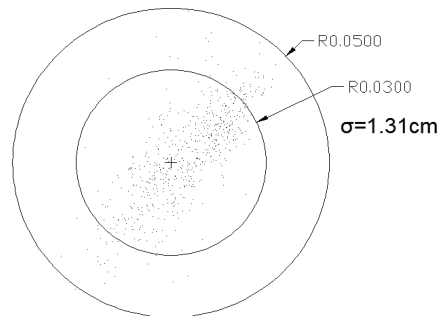


Figure 5.13 Horizontal error in urban canyon

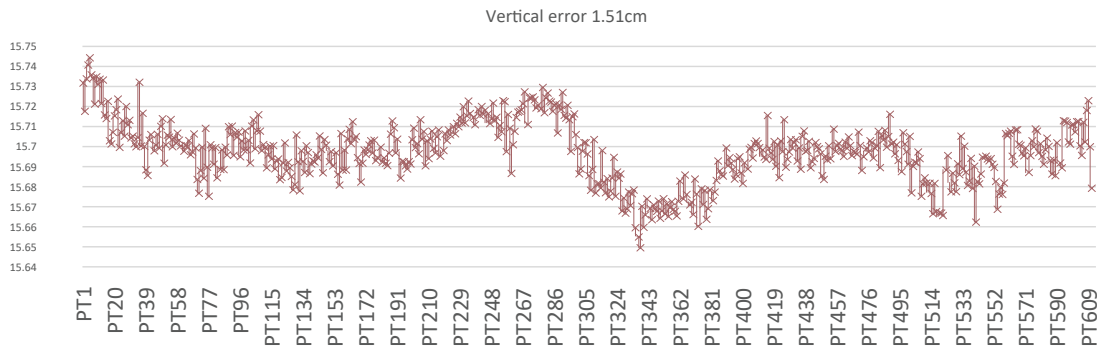


Figure 5.14 Vertical error in urban canyon environment

## 5.5 Availability and accuracy at tilt angles greater than 90 degrees

When would a surveyor choose to measure with a tilt angle of greater than 90 degrees? For instance, under an overhang, or reaching up to point on the side of building or embankment. In such instances, surveyors could not otherwise use GNSS, but instead might need to use a total station for an offset. For most GNSS systems, tilt compensation at angles over 45 or 60 degrees is not possible or yields insufficient accuracy. Our confidence in the ExtremeRTK™ tilt compensation, coupled with the advanced antenna design of the Tersus Oscar rovers, led us to conduct such unprecedented tests.

To demonstrate the tilt compensation availability and accuracy when the tilt angle is greater than 90 degrees, the testing steps were as follows:

1. A point that can be measured with tilt compensation at an angle greater than 90 degrees is selected.

2. With the tilt compensation function off, four measurements in four cardinal directions were taken and averaged as the control value. Then, 18 points were collected at angles greater than 90 degrees in 30 attempts. For the other 12 attempts, it was shown that the tilt compensation was disabled or the RTK solution status was float.

This demonstrated an availability  $\delta (>90^\circ \text{ IMU}) \approx 60\%$ .

Figure 5.19 shows an RMS of 0.037m for the 22 points when tilt compensation is available, at an average angle of about 110 degrees. It can be seen that the tilt compensation can still maintain high accuracy, with operator diligence, even when the tilt angle is greater than 90 degrees, which could meet users' special requirements in such scenarios.



Figure 5.15  
measure without  
tilt compensation



Figure 5.16  
measure without  
tilt compensation

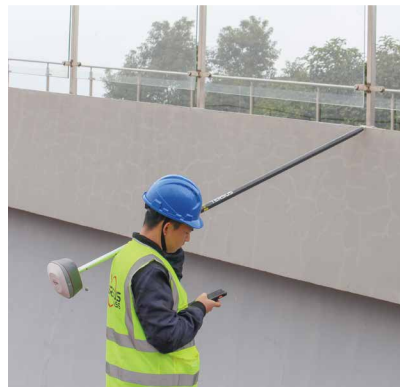


Figure 5.17 measure at  
tilt angle greater than 90°

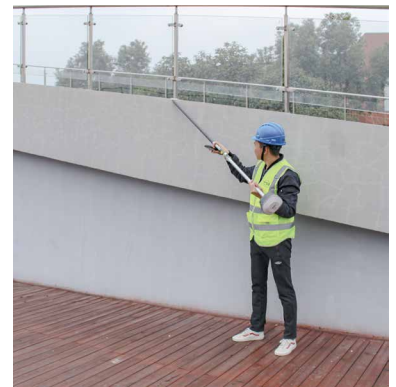


Figure 5.18 measure at  
tilt angle greater than 90°

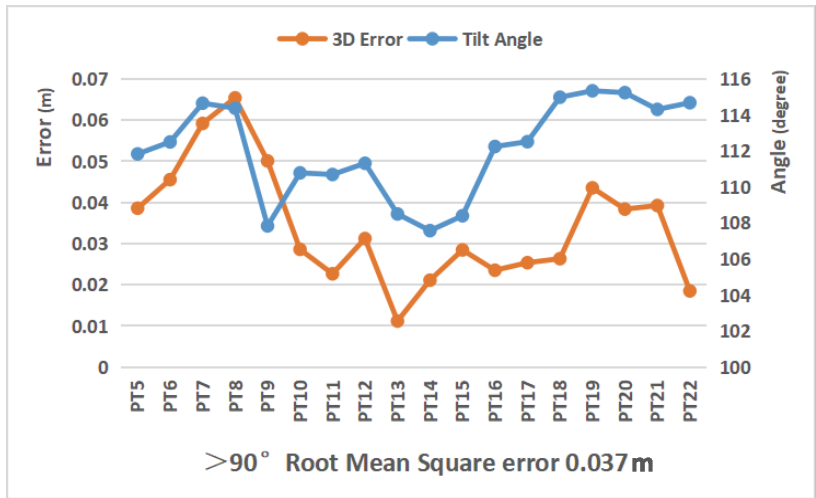


Figure 5.19 3D error at tilt angle greater than 90 degrees

## 5.6 New methods for topographic surveys

ExtremeRTK™-powered tilt compensation solution has excellent performance in initialization speed, available rate, and accuracy. This enables unprecedented methods for topographic surveying. Taking earthwork volume survey as an example, it:

- Allows surveyors to drag the poles or use Tersus ROD-TIP-ROLLER for continuously surveying without leveling;
- Accuracy is not necessarily dependent on the capabilities of the surveyor; meanwhile, higher accuracy is achieved while efficiency is greatly improved;
- Denser and more accurate TINs (triangulated irregular

model) can be achieved—more points can be collected in the same amount of time.

To demonstrate the efficiency and accuracy of these new methods for topographic surveying, an area of 5.7m x 38.7m was selected for testing. The results show that **compared with a traditional RTK measurement method (stop and level the pole), the efficiency of the new method utilizing tilt compensation on foot is improved by 85%, and the spatial difference between the two methods is only 2.3%.**

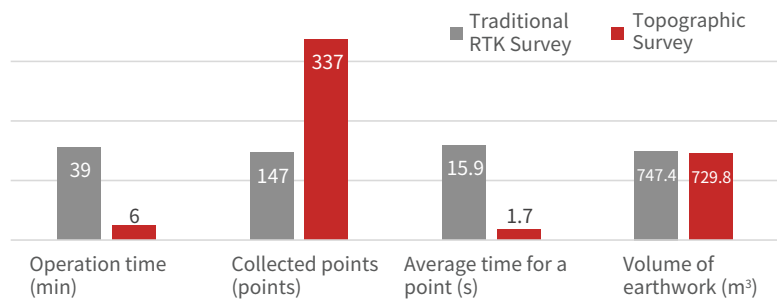


Figure 5.20 Comparison between traditional RTK survey and topographic survey

## 5.7 3D visualization stakeout

Stakeout is one of the most important tasks in engineering and construction surveying. Without the tilt compensation function, measuring each point requires a single leveling step. But to stakeout a point, the surveyor needs to take repeated measurements as they get closer to the desired stakeout point, leveling the pole each time—this is very time consuming. When tilt compensation is used, looking

at the level bubble is no longer needed, and the surveyor only needs to focus on finding the point on the ground by moving the pole tip. Additionally, for the tilt compensated stakeout solution based on ExtremeRTK™, the 3D visualization stakeout function can be enabled by checking 'Rotate Map During Stakeout' in Nuwa (Tersus's versatile field software) display configuration.

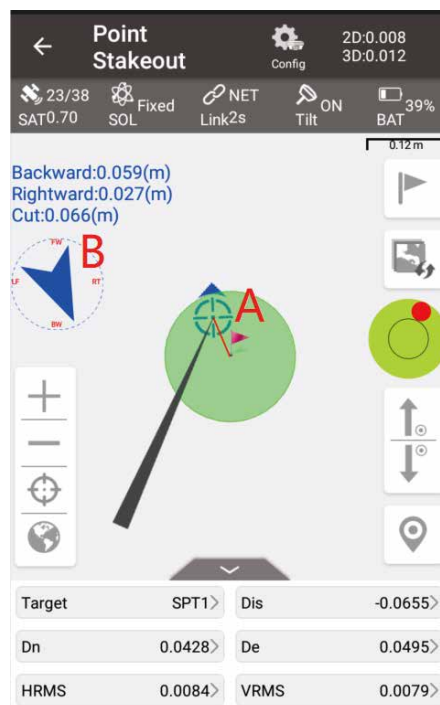


Figure 5.21 Tilt compensated stakeout in Nuwa

The arrow A in the figure above indicates the receiver's direction and B indicates the moving direction of the pole tip. When starting to stakeout a point, make sure that the receiver display panel is facing you and select a stakeout point, then rotate arrow A (rotate the pole) to the staking point, and then work forward. When surveyor is closed to the staking point, the pole tip can be adjusted according to the arrow B indication. This is easy to achieve:

- Nuwa features intuitive 3D stakeout instructions; the pole's status can be displayed in real time with the 10Hz refresh rate and the user can quickly determine the orientation and the approximate distance of the current position to the point to be staked;
- Near the stakeout point, the position can be quickly determined by sliding the pole tip against the ground, without leveling point by point;
- No need to find north point by point during stakeout, which improves the accuracy and efficiency as well as reduces the workload.

To demonstrate this, an application scenario of road centerline stakeout is selected with a road section length of 27.5m. The centerline is staked out at 1m intervals. The two methods of traditional RTK and tilt compensated stakeout are performed. The stakeout time and accuracy were

counted (using the value of traditional RTK stakeout as the control). **The results show that compared with the traditional RTK method, the efficiency of tilt stakeout is improved by about 50%, and the deviation in root mean square error is only 1.48cm.**

Comparison item	Tilt stakeout	Traditional RTK stakeout
Operation time (min)	16	32
Staking points (points)	29	29
Average time for a point (s)	33	66

Table 5.2 Comparison between tilt stakeout and traditional RTK stakeout

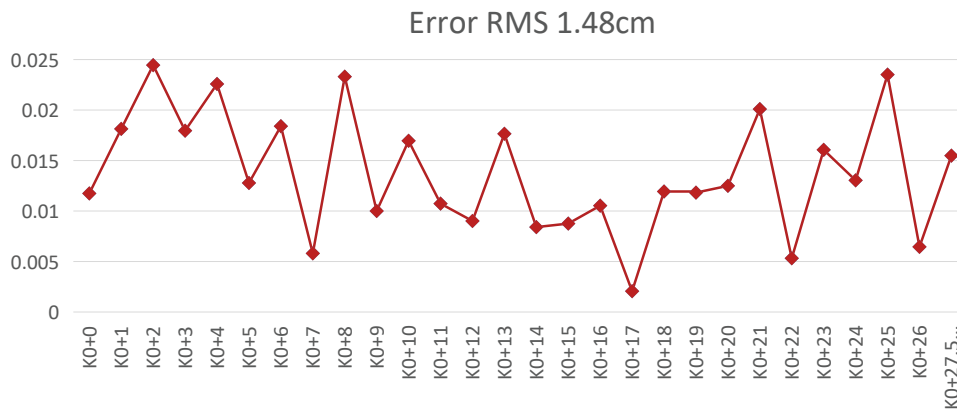


Figure 5.22 Root mean square error of tilt stakeout

## 6. Conclusion

As indicated from the test results presented in this white paper, ExtremeRTK™ has remarkable performance in **RTK initialization, accuracy, tilt compensation**, etc., and possesses the strengths that international mainstream brands do. Based on ExtremeRTK™, we will continue to invest in the further development of RTK Receivers by adding photogrammetry, laser scanning, and more. Meanwhile, we will also focus R&D in professional industry software, the integration of resources in data

management, and big data applications so as to provide users with additional professional services. These will include but are not limited to global CORS raw data download, Network RTK services, precision ephemeris download, high-precision ionospheric/tropospheric models, and fast PPP (precise point positioning). Thus, the Tersus portfolio and ecosystem will continue to grow to bring more possibilities and convenience for users and their applications.

To learn more, please visit: [www.tersus-gnss.com](http://www.tersus-gnss.com)

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