Improvement of Digital Guidance for Tracking of the Last Stage of a Shipborne Unmanned Antenna

Liu Yang, He Jing

China Satellite Maritime Tracking and Control Department, Jiangyin, 214431, China

Abstract. This paper proposes its background from an unmanned antenna needs digital guide to lead it to accomplish getting the target to existing digital guide for initiative Aerospace measurement has a poor accuracy. Then the principles of three major errors of digital guide namely time difference, visual difference and delaying accumulation error are explained and thus each method to each error has been given.

1. Introduction

A ship-borne unmanned self-tracking antenna is mainly used for the end tracking measurement of high-speed flying targets in the offshore environment (nearly several tens of kilometers to several kilometers). It uses a parabolic antenna with a diameter of 1.5m, beam width close to 6°, wind load and moment of inertia are only one-tenth of the large measuring antenna (caliber more than 10m), which is very suitable for tracking high dynamic targets at sea. However, the unmanned mode means that the antenna cannot capture the target by the traditional waiting point manual scanning search, and must use the computer digital guidance (referred to as digital guidance) or program guidance to achieve automatic capture of the target. This requires digital guidance to have sufficient accuracy - better than the antenna's tracking accuracy (tracking accuracy of 0.5°), the digitally guided model comes from the existing model of the offshore space active segment measurement task, and the digital guidance of the active segment measurement Generally only used as a reference for manual capture, the accuracy often fails to meet this requirement. In addition, the particularity of the last trace also makes certain device problems stand out—such as the digital boot delay accumulation problem, which must be improved.

2. Digital guidance time difference extrapolation correction

The digital guidance data tracked at the end of the antenna is inferred from the measured ballistic extrapolation of the telemetry device at the head/site. The main error affecting the accuracy of digital guidance is the delay error. According to the data transmission process, the delay error can be divided into two parts: one is to measure the delay error of the ballistic machine to the ship center machine; the other is the delay error from the center machine to the antenna drive unit.

For the first part of the delay error, take the target GPS data as an example: at a certain moment, the data measured by the target GPS receiver is \((T_1,X_1,Y_1,Z_1,V_{X1},V_{Y1},V_{Z1})\), and the data passes the first/stop. Regional delivery. The downlink receive link of the telemetry equipment, the data processing center of the first/aviation area, and the central and downstream links that are transmitted to the ship station at the highest, there must be a delay in the reception, calculation and transmission of data. In the middle, therefore the central machine data will be received and converted to digital pilot data \((T_1,A_{i1},E_{i1},V_{Ai1},V_{Bi1})\) pointing to the antenna at time \(T_2\) after time \(T_1\), but since the target is moving...
and moving at high speed, time $T_2$. The target position at the location is no longer at the angular position pointed by the digital boot data (the position indicated by the digital guide should be the lead position corresponding to time $T_1$), and the measurement result indicates that the delay can reach $2\,\text{s}$ and the obtained Digital guidance error angle $\pm 3^\circ \sim \pm 5^\circ$. Part of the time difference correction method given by the digital guidance model for active part aerospace measurement is: ship time system $T_2$ and data $(T_1, X_1, Y_1, Z_1, V_{X1}, V_{Y1}, V_{Z1})$ when the central machine receives data. The time scale $T_1$ in the frame is $\Delta T = T_2 - T_1$, and then extrapolated correction data $(T_2, X_2, Y_2, Z_2, V_{X2}, V_{Y2}, V_{Z2})$ are obtained by speed component integration or interpolation. Delay correction is measured continuously in real time - guaranteed by the on-time accuracy of the ship's time and target time, so the time difference correction for this part can directly follow the original model.

However, for the second part of the delay, that is, the transmission and processing delay of the center-to-antenna drive unit, the original model cannot be used, because the antenna of the active section only receives the digital guidance data from the measurement system sent by the central unit during the aerospace measurement of the active segment (The center of the three axes of the antenna is the azimuth of the coordinate origin and the data of the pitch deck angle) and directly drives the antenna to operate. Therefore, the processing delay of the center machine to the drive unit is not considered, and only the upper control device of the center machine to the drive unit is considered. The network transmission delay of the control unit (general term: ACU) is generally 50ms, so the correction amount of the original model is: $\Delta T = T_2 - T_1 + 50\,\text{ms}$. The ACU of this device takes into account the particularity of the unmanned mode, and the processing is more complicated - in addition to being able to process the digital boot data under the measurement system, it is also able to process the digital boot data under the inertial navigation system - ie The whole ship inertial navigation reference platform is the azimuth and elevation earth angle data of the origin. The data can't directly drive the antenna, and the land angle and ship position data provided by the inertial navigation must be used to complete the conversion from the ground angle to the deck angle. Therefore, the processing is implemented in software—that is, using the kernel program of the FPGA device. The software processing delay will increase significantly - the monitoring software at the top of the ACU reaches the underlying FPGA kernel through the intermediate driver layer. The delay is about 50ms. Therefore, the digital boot data extrapolation correction of the central unit should be $\Delta T = T_2 - T_1 + 100\,\text{ms} $.

3. Digital guided parallax correction

As mentioned above, the ACU can process the digital guidance data of the inertial navigation system sent by the central machine. The coordinate origin of the data is the center of the inertial reference platform of the whole ship, not the three-axis center of the antenna base, so the number The guiding data has parallax, and the closer the target distance is, the smaller the visual distance is, the larger the parallax effect is. The lower limit of the tracking is as follows: elevation angle 750, target distance antenna height 1km (target flight height is the same, line of sight) The smaller the angle, the higher the elevation angle. For example, the parallax of the elevation angle is analyzed geometrically. For the azimuth parallax, the ship's rifling can be kept as close as possible to the target's flight direction by adjusting the heading. At this time, the azimuth parallax is close to 0 (this measurement condition makes the azimuth almost neither at the end. The change is beneficial to the whole process of tracking the target, usually using this condition design), so only the parallax of the elevation angle is analyzed.
Figure 1. Schematic diagram of the geometric relationship of the parallax formation under the inertial navigation deck

Taking the inertial reference platform as the origin O, the direction of the nautical plane on the sea level is the X-axis, the direction perpendicular to the X-axis on the horizontal plane is the Z-axis, and the space is established by the Y-axis perpendicular to the horizontal plane. The coordinate system is the inertial deck system, as shown in Figure 1. The difference between the three points of the antenna's three-axis center and the center of the inertial navigation platform in the three axial directions is: the X-axis is 1m apart, the Y-axis is 17m, and the Z-axis is 0.04m (that is, the center point is located inside the hull) On the central axis, it can be ignored.) Therefore, the three-axis center coordinate B (1, 17, 0) of the antenna is in m (the unit is the same). Here $\angle AOE=75^0$, $AE=1000$, $OD=1$, $CE=BD=17$.

The current position of the target flight shall be a point at the circumference of the bottom surface of the inverted cone with O as the apex, the Y axis as the central axis, the height being 1000 m, and the apex angle $\angle AOF=180^0-2\angle AOE=180^0-2\times75^0=30^0$.

Then, $OA=AE/\sin(\angle AOE)=1035$, $OE=OH=O\cos(\angle AOE)=267$.

$AC=AE-CE=983$, $BC=DE=OE-OD=266$, $\angle ABC=\arctan(AC/BC)=74.86^0$.

$BG=DH=OH+OD=268$, $FG=AC=983$, $\angle FBG=\arctan(FG/BG)=74.75^0$.

It can be proved that BA and BF are the shortest and longest radial diameters from point B to the circumference of the bottom of the cone, respectively, so the angle $\angle ABC$ and the angle $\angle FB$ are the maximum and minimum elevation angles of the target to the antenna, respectively, so the minimum and maximum elevation angle parallax They are $75^0-\angle ABC=0.14^0$ and $75^0-\angle FB=0.25^0$, respectively. The simplest method of parallax correction is that the central machine software directly superimposes the coordinate correction amount of the inertial navigation platform to the antenna triaxial center to the ship position information and sends it to the antenna ACU without changing the digital boot conversion under the inertial navigation system in the original software model.

4. Solution to the problem of digital boot delay accumulation

The frame rate of the digital guidance data transmitted by the central unit specified in the digital guidance model of the active section aerospace measurement is 20 frames/s, that is, one frame of data is transmitted in 50 ms. In order to ensure that the antenna runs smoothly and continuously without creeping, the ACU usually performs internal interpolation processing on the digital pilot data. For example, the data of 50 ms frame is interpolated into data of 100 frames/s or 10 ms, so insert two values of the difference of the difference between the two frames of transmission data. As shown in Figure 2, insert $B_1$ to $B_4$ between $A_1$ and $A_2$, and make $A_1B_1B_2B_3B_4A_2$ form an arithmetic progression column. After the interpolation is completed, write each group of 5 numbers $A_1B_1B_2B_3B_4$. Drive layer...
buffer. Since the number of writes and the reading are not synchronized - the write interrupt of the write number is the clock signal sent by the central machine, the interrupt generation time writes a set of 5 data to the buffer at one time, and the sampling interrupt of the reading is interrupted by the ACU local timer. Generated, that is, the ACU timer sends the sampling interrupt to read the buffer data every 10ms. Because there is a clock difference between the central machines transmit clock and the ACU timer, the digital guide will form a large delay error with the accumulation of time. - Up to 1 s delay.

![Figure 2. Digital pilot interpolation delay accumulation diagram](image-url)

It is assumed here that the write interrupt interval sent by the central machine is exactly 50ms. Since the write data is completed once (a set of 5 data write operations has been completed before the next write interrupt arrives), each data is equivalent. The write interrupt interval is equivalent to 10ms, and if the interrupt interval of the reading is also 10ms, there will be no delay accumulation problem. However, there is a delay error in the read sample interrupt generated by the ACU timer - based on the measured value of approximately 0.001 ms, that is, the actual timed read interrupt is 10.001 ms. As shown in Figure 2, the data is read by 0.001ms per sample, that is, the antenna receives the data with a delay of 0.001ms, so that the cumulative delay will reach 0.001ms (100ms/10ms) every 100s. 10ms, just equal to the time of writing a timer interrupt, that is, the read time is slower than the write time, so the next write data can only be written to the next position of the buffer, so as to ensure the last future. The data being read is not overwritten, thereby acting as a buffer for data. By analogy, every n 100s time reading is slower (10×n) ms, the buffer is increased by n. However, the space of the driver layer buffer is limited - only 100 frames of data are buffered, that is, 10ms × 100 = 1s of data. After that, when new data arrives, the buffer has no new space to write, and only the current read can be overwritten. Taking the position of the data, so that the timing of sampling read and write data is re-aligned, so the cumulative error of the digital boot data is not more than 1 s, which is consistent with the actual situation.

The above-mentioned delay accumulation problem is not exposed in the active section aerospace measurement because the active section measurement time is relatively short - no more than 300s, and the cumulative delay formed does not exceed (300s/100s) × 10ms = 30ms. This error can be ignored. The time of tracking the end of the unmanned antenna is sometimes as long as 3 hours or 10800s, and the maximum cumulative delay is (10800s/100s) × 10ms = 1080ms, which has exceeded the maximum delay that the buffer can carry. -1s, so the cumulative error of delay is 1s at this time, and the resulting digital guiding angle error can reach 30. Obviously, the error can not be ignored, and this error must be solved from the root source - improve the read and write operations on the device side.

Through the above analysis, it can be seen that the root cause of the delay accumulation is that the reading and writing actions are not completed synchronously, the writing number is fast, the reading action is slow, and the reading is slower than the writing number. If the number of writes required is the same as the number of readings, it will inevitably cause the reading to be less than the number of
writes, that is, the problem of missed reading. Therefore, the simplest and most effective solution for this situation is to keep the number of readings unchanged and reduce the writing. The number of inputs, that is, the way of underwriting, in other words, reducing the number of interpolations for the digital boot data, inserting 4 numbers between every 2 frames of data into 3 numbers, and after inserting each group of 4 The data is written to the driver layer buffer once. This is equivalent to reducing the speed of writing data - from the original 10ms to 50ms / 4 = 12.5ms, and the data is still unchanged every time the interrupt is sampled - still 10.001ms, that is still pressed Read 5 times every 50ms, but only 4 numbers of data are written at this time (1 number is the digital boot value sent by the center machine, 3 numbers are interpolated), so a repeated reading process will be generated (read is according to The principle of sequential reading - if no new data is taken when the sampling interrupt arrives, the previous value is read repeatedly. Although the repeated reading is not conducive to the continuous and even operation of the antenna, the effect is very small for a very short time (12.5ms) - after the delay correction according to the above method, the actual running antenna works well and there is no creeping phenomenon.

5. Conclusion
The above is the three most important steps considered for the improvement of digital guidance, but there are many error sources for digital guidance, such as the antenna's large disk non-levelness, angle zero value, various shafting errors and photoelectric deviation errors. These factors are the secondary links of the digital guidance error, and the influence is very small, and the system error items such as the angle zero value are also corrected from the equipment end by the calibration in the dock, so the correction problem of these error terms can be ignored. The accuracy of the digital guided data after the above improvement has been verified by many actual flight tests: the antenna capture target is fast, accurate and stable, which advantageously ensures the reliability of the automatic capture target in the unmanned mode.

References
[1] Zhang Yi, Yang Huiyao, Li Junli. Ballistic Missile Ballistics [M]. Changsha: National University of Defense Technology Press, 1999
[2] Zhong De'an. Standardization and school flight technology of spacecraft measurement and control communication equipment [M]. Beijing: National Defence Industry Press, 2009.1