ATO

ATO-HEC3500D-MB 6-axis Compass Sensor User Manual

1. Product Introduction

The ATO HEC3500D-Modbus protocol series is a high-precision, full-attitude six-axis electronic compass. It integrates three-axis fluxgate sensors, accelerometers, an industrial-grade MCU, and driver chips. By combining an inclination compensation patented algorithm, the compass provides heading compensation over a wide range of tilt angles.The product adopts hard iron and soft iron magnetic interference compensation technologies to eliminate magnetic field disturbances. With an optimized Extended Kalman Filter (EKF) algorithm, it improves the dynamic and static measurement performance of the magnetic compass, enabling the central processor to calculate accurate heading and attitude data in real time even under extremely harsh environmental conditions. Customized solutions are also available according to customer requirements.

The product can be widely applied in various fields, including photovoltaic tracking systems, oil and geological well exploration, optical rangefinders, GPS-assisted navigation, marine surveying, underwater navigation, and mechanical control systems.

2. Main Features

- Heading accuracy: 0.3° (RMS); tilt accuracy: 0.02°;
- Measurement output: Pitch ±90°, Roll ±180°, Yaw 0–360°;
- Optional communication interfaces: RS232 / RS485 / TTL / RS422;
- Input voltage: DC 5V (DC 9–35V customizable);
- Compact size: 125 × 22 × 24 mm (customizable);
- Tilt range: ±90°;
- Aviation connector;
- Supports hard iron, soft iron, and tilt compensation;
- Wide operating temperature range: -40 to +85°C;
- Protection rating: IP67 (IP68 customizable).

3. Applications

- Satellite antenna servo control;
- Automatic solar photovoltaic tracking systems;
- Pitch and yaw angle measurement for ship navigation and surveying;
- Launch systems;
- ROV (Remotely Operated Vehicle) underwater robot navigation;
- Robotic arms for special applications;
- Oceanographic survey instruments;
- AGVs (Automated Guided Vehicles) and unmanned patrol vehicles;
- GPS integrated navigation systems.

Product Performance Specifications

Parameter	Condition	HEC3500D-MB
Compass Heading Parameters	Heading accuracy	0.3°
	Resolution	0.05°
	Repeatability	0.1°
	Tilt range	Pitch ±90°, Roll ±180°
Compass Tilt Parameters	Pitch accuracy	0.02°
	Roll accuracy	0.02°
	Resolution	0.005°
Calibration	Hard iron calibration	Available
	Soft iron calibration	Available
	Tilt calibration	Available
Long-term Stability	-40-85°C	<0.5°
Power-on Startup Time	0.15 s	
Response Time	0.1 s	
Automatic Output Rate	5 Hz output, 15 Hz, 35 Hz, 50 Hz adjustable (RS485 not supported)	
Output Signals	RS232, RS485, RS422, TTL optional	
Mean Time Between Failures (MTBF)	≥45,000 hours	
Shock Resistance	20,000 g, 0.5 ms, 3 times/axis	
Vibration Resistance	10 grms, 10–1000 Hz	
Insulation Resistance	≥100 MΩ	
Protection Rating	IP67 (IP68 customizable)	

Cable	Standard 1.5 m length, wear-resistant, oil-resistant, temperature-resistant, shielded signal cable 5×0.2 mm^2
Weight	130 g (excluding packaging)

Electrical Specifications

Parameter	Condition	Min	Typical	Max	Unit
Supply Voltage	Standard		5		V
	Customized	9	12, 24	35	
Operating Current	No load		35		mA
Operating Temperature		-40		+85	°C
Storage Temperature		-55		+125	°C

Teminology

• Resolution: The minimum change in the measured parameter that the sensor can detect and distinguish within its measurement range.

• Accuracy: The comprehensive error of the sensor under normal temperature conditions, including absolute linearity error, repeatability error, hysteresis error, zero-point deviation, and cross-axis error.

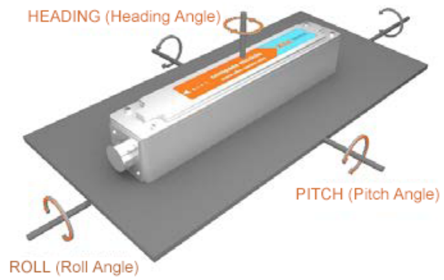
• Long-term Stability: The deviation between the maximum and minimum values after one year of continuous operation under normal temperature conditions.

•Response Time: The time required for the sensor output to reach the specified value after a single angular change.

Product Measurement Direction & Mounting Method

During installation, the sensor mounting surface should be kept parallel to the target surface being measured. The product supports horizontal installation (default) and vertical installation (optional). Please refer to the installation diagram for details.

Vertical Installation



Horizontal Installation

Since the yaw angle measurement of the HEC3500D is based on the geomagnetic principle, selecting an installation location with minimal magnetic interference is critical. The sensor should be kept as far away as possible from iron materials, magnets, engines, and other magnetic objects. A minimum distance of 50 cm or more is recommended (the required distance may vary depending on the type and strength of magnetic interference).M4 stainless steel screws must be used for installation. Please note that this product can compensate for moderate deviations in a stable magnetic environment, but it cannot compensate for changing magnetic interference.

Special attention should be paid to magnetic fields generated by DC power cables, as changes in DC current will also cause changes in magnetic field strength. Batteries are another potential source of variable magnetic interference. Since every installation environment is different, users must evaluate installation feasibility under all possible operating conditions.

The HEC3500D can achieve a maximum heading accuracy of 0.3°. This performance has been strictly verified through rigorous testing. Therefore, selecting a scientific and reliable testing method is equally important.

Recommended test method: Install the HEC3500D electronic compass on a vertically mounted aluminum rod (or a rod made of other non-magnetic materials) and perform heading accuracy measurements. During testing, ensure that the rod is perpendicular to the rotating platform and minimize external magnetic interference as much as possible. This method can reduce the rotation radius of the compass and improve measurement accuracy.

This method is only a recommended approach. Users should select an appropriate installation method according to their actual application conditions. For example, when installed on a vehicle, the HEC3500D should be mounted perpendicular to the direction of travel.

Mechanical Specifications

- Connector: 1.5 m lead wire or waterproof aviation connector (customizable);
- Protection Rating: IP67;
- Housing Material: Aluminum alloy with matte anodized finish;
- Installation: Two M3 screws.

Calibration Method

The electronic compass has been factory calibrated. In environments with no or minimal magnetic interference, no additional calibration is required and the product can be used directly.

Calibration is required under the following conditions:

1. The measured heading accuracy does not meet the required precision.

2. The compass installation environment has magnetic interference, and this interference is fixed but changes after installation.
For example, when the compass is installed on a steel material, the steel structure will introduce magnetic interference. In this case, the steel material and the compass must be calibrated together. If the compass is removed from the installation position after calibration, it must be recalibrated before reuse.

The HEC3300D electronic compass has been factory calibrated under a non-magnetic environment. When used in an environment without magnetic interference, no additional environmental calibration is required.

When ferromagnetic materials or conductive metals are present around the compass (such as iron, steel, batteries, microphones, high-current coils, or motors), the surrounding geomagnetic field will be distorted, causing magnetic interference to the compass. Hard iron interference refers to a constant magnetic field generated by fixed magnetic sources, such as permanent magnets; soft iron interference refers to a magnetic field that can be distorted or changed by external magnetic fields, such as iron plates.

In such cases, environmental calibration is recommended. During calibration, the surrounding interfering objects must maintain their relative positions unchanged while the compass is rotated. The compass can then learn the surrounding magnetic environment and compensate for the effects of hard iron and soft iron interference, improving measurement accuracy.

Note: During environmental calibration, operators should remove objects that may affect the magnetic field, such as mobile phones, keys, and other metal objects or electronic devices.

The following section introduces five magnetic environment calibration methods. For most application scenarios, automatic 12-position calibration is recommended as the first step.

1. Automatic 12-Position Calibration

After starting the calibration process, rotate the compass to the approximate attitude positions shown in the table below (precise alignment is not required). Once the compass reaches a suitable position, it will automatically collect data points. The compass can collect data from a maximum of 12 positions.

Sampling No	Heading (°)	Pitch (°)	Roll (°)
1	0	-5~+5	30~40
2	90	-5~+5	-30~-40
3	180	-5~+5	30~40
4	270	-5~+5	-30~-40
5	30	>+45	30~40
6	120	>+45	-30~-40
7	210	>+45	30~40
8	300	>+45	-30~-40
9	60	<-45	30~40
10	150	<-45	-30~-40
11	240	<-45	30~40
12	330	<-45	-30~-40

Calibration Procedure

A. Fix the electronic compass in the actual operating environment. During calibration, rotate the compass together with other equipment that may affect its magnetic environment.

B. Send the following calibration command in hexadecimal format: 77 04 00 63 67.

C. Rotate the compass to the required attitudes according to the above table.

D. After successful sampling, the compass will return the command 77 04 00 66 followed by 15 bytes, including 1 byte of magnetic interference value, 1 byte indicating the number of valid sampling points, and 1 byte of checksum. The number of valid sampling points refers to the number of magnetic field data samples collected by the compass for calibration calculation.

E. If calibration needs to be exited, send the stop calibration command in hexadecimal format: 77 04 00 12 16

F. After completing the calibration, send the hexadecimal command 77 04 00 09 0D to save the calibration data. If the calibration data is saved successfully, the compass will return the hexadecimal command: 77 09 00 89 FitErr YY (refer to the command list for details). Among them, FitErr represents the calibration error. A smaller value indicates better calibration performance. If this value is greater than 10, recalibration is required. YY is the checksum.

2. Manual Calibration

The principle of manual calibration is to rotate the compass to the positions where it will actually be used and collect more calibration points. For example, if you know that the compass will be used at 0° roll and 30° pitch, then during calibration, place the compass at approximately 0° roll and 30° pitch and select multiple calibration points. For other pitch and roll angle positions, fewer calibration points can be selected, while the heading angle positions should be selected evenly. After rotating the compass to a specific position, manually send the command to save the calibration point. Multiple calibration points can be collected according to actual requirements (at least 12 points are recommended). The compass compensates for surrounding magnetic field interference based on the data collected at different attitudes.

Calibration Procedure

A. Fix the electronic compass in the actual operating environment. During calibration, rotate the compass together with other equipment that may affect its magnetic environment.

B. Send the following calibration command in hexadecimal format: 77 04 00 65 69.

C. Rotate the compass to the required attitude and send the command: 77 04 00 67 6B to save the calibration point.

D. After successful sampling, the compass will return the command 77 04 00 66 followed by 15 bytes, including 1 byte of magnetic field data, 1 byte indicating the number of valid sampling points, and 1 byte of checksum. The number of valid sampling points indicates the number of magnetic field samples collected by the compass for calibration calculation.

E. If calibration needs to be exited, send the stop calibration command in hexadecimal format: 77 04 00 12 16.

F. After completing the calibration, send the hexadecimal command: 77 04 00 09 0D to save the calibration data. If the calibration data is saved successfully, the compass will return the hexadecimal command: 77 09 00 89 FitErr YY (refer to the command list for details). FitErr represents the calibration error. A smaller value indicates better calibration performance. If the value is greater than 10, recalibration is required. YY is the checksum.

3. Automatic Full-Attitude Calibration

The principle of automatic full-attitude calibration is to rotate the compass through as many different attitudes as possible. The combinations of tilt, pitch, and heading angles should cover all attitudes. The compass will automatically collect appropriate data points, and more collected data points will result in more accurate calibration. A maximum of 96 calibration points can be collected. This method provides the most accurate calibration theoretically.

Calibration Procedure

A. Fix the electronic compass in the actual operating environment. During calibration, rotate the compass together with other equipment that may affect its magnetic environment.

B. Place the compass in a horizontal position.

C. Send the following calibration command in hexadecimal format: 77 04 00 08 0C.

D. Rotate the compass around the Z axis (Z-axis direction perpendicular to the ground). Rotate 2–3 turns. During rotation, try to use variable-speed rotation, such as accelerating → decelerating → accelerating → decelerating. One full rotation should be completed within approximately 10–15 seconds.

E. Rotate the compass around the X axis and Y axis. During rotation, use slow and uniform rotation. Rotate around each axis for 1–2 turns. The rotation time for each axis is approximately 10 seconds.

F. Rotate the compass randomly. Slow and uniform rotation is recommended during the process. The rotation axis should avoid coinciding with the rotation axes used in Steps D and E as much as possible, while ensuring that the compass covers as many different attitudes as possible.

G. After successful sampling, the compass will return the command 77 04 00 66 followed by 15 bytes, including 1 byte of magnetic field data, 1 byte indicating the number of valid sampling points, and 1 byte of checksum. The number of valid sampling points indicates the number of magnetic field samples collected by the compass for calibration calculation.

H. If calibration needs to be exited, send the stop calibration command in hexadecimal format: 77 04 00 12 16.

I. After completing the calibration, send the hexadecimal command: 77 04 00 09 0D to save the calibration data. If the calibration data is saved successfully, the compass will return the hexadecimal command: 77 09 00 89 FitErr YY (refer to the command list for details). FitErr represents the calibration error. A smaller value indicates better calibration performance. If this value is greater than 10, recalibration is required. YY is the checksum.

4. Automatic 12-Position Calibration for Small Tilt Angles

This calibration method is designed for applications with small tilt variations, where the Roll angle change is less than 5°. After starting the calibration process, rotate the compass to the attitude positions shown in the table below. Once the compass reaches the appropriate position, it will automatically collect data points. The compass can collect a maximum of 12 calibration points.

Sampling No	Heading (°)	Pitch (°)	Roll (°)
1	0	-5~+5	-5~+5
2	90	-5~+5	-5~+5
3	180	-5~+5	-5~+5
4	270	-5~+5	-5~+5
5	30	>+45	-5~+5
6	120	>+45	-5~+5
7	210	>+45	-5~+5
8	300	>+45	-5~+5
9	60	<-45	-5~+5
10	150	<-45	-5~+5
11	240	<-45	-5~+5
12	330	<-45	-5~+5

Calibration Procedure

A. Fix the electronic compass in the actual operating environment. During calibration, rotate the compass together with other equipment that may affect its magnetic environment.

B. Send the following calibration command in hexadecimal format: 77 04 00 64 68.

C. Rotate the compass to the appropriate attitude according to the requirements above.

D. After successful sampling, the compass will return the command 77 04 00 66 followed by 15 bytes, including 1 byte of magnetic field data, 1 byte indicating the number of valid sampling points, and 1 byte of checksum. The number of valid sampling points indicates the number of magnetic field samples collected by the compass for calibration calculation.

E. If calibration needs to be exited, send the stop calibration command in hexadecimal format: 77 04 00 12 16.

F. After completing the calibration, send the hexadecimal command: 77 04 00 09 0D to save the calibration data. If the calibration data is saved successfully, the compass will return the hexadecimal command: 77 09 00 89 FitErr YY (refer to the command list for details). FitErr represents the calibration error. A smaller value indicates better calibration performance. If this value is greater than 10, recalibration is required. YY is the checksum.

5. Plane Calibration

This calibration method is suitable for applications where the compass is only used on a plane with minimal tilt. After starting the calibration process, rotate the compass slowly and uniformly by one full circle within the plane. During the rotation, the compass will automatically collect appropriate data points. A maximum of 12 calibration points can be collected.

Calibration Procedure

A. Fix the electronic compass in the actual operating environment. During calibration, rotate the compass together with other equipment that may affect its magnetic environment.

B. Place the compass in a horizontal position.

C. Send the following calibration command in hexadecimal format: 77 04 00 60 64.

D. Rotate the compass slowly and uniformly by one full circle on the horizontal plane as required.

E. After successful sampling, the compass will return the command 77 04 00 66 followed by 15 bytes, including 1 byte of magnetic field data, 1 byte indicating the number of valid sampling points, and 1 byte of checksum. The number of valid sampling points indicates the number of magnetic field samples collected by the compass for calibration calculation.

F. If calibration needs to be exited, send the stop calibration command in hexadecimal format: 77 04 00 12 16.

G. After completing the calibration, send the hexadecimal command: 77 04 00 09 0D to save the calibration data. If the calibration data is saved successfully, the compass will return the hexadecimal command: 77 09 00 89 FitErr YY (refer to the command list for details). FitErr represents the calibration error. A smaller value indicates better calibration performance. If this value is greater than 10, recalibration is required. YY is the checksum.

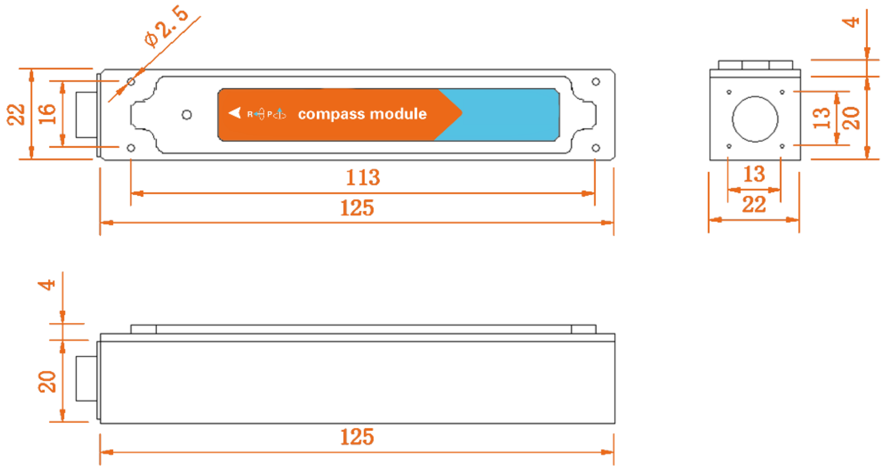
The five calibration methods and their characteristics are shown below. Users can select the appropriate calibration method according to their actual application requirements.

Calibration Method	Suitable Calibration Conditions	Calibration Evaluation	Application Limitations
Manual Calibration	Select calibration points based on known pitch and roll angle ranges. Perform calibration using the most commonly used attitudes.	Best calibration effect when the selected calibration points are appropriate.	Improper selection of calibration points may seriously affect calibration performance.
Automatic Full-Attitude Calibration	The compass and the corresponding fixed structure can rotate in all directions, and the magnetic environment is complex.	Overall calibration performance is good, with the highest accuracy in complex magnetic environments.	Requires the compass and fixed structure to be able to rotate in all directions.
Automatic 12-Position Calibration	The compass and corresponding fixed structure can rotate at fixed positions.	Provides better calibration results, but the accuracy in complex magnetic environments is lower than that of automatic full-attitude calibration.	Pitch angle must be ≥45°, and Roll angle must be >30°.
Automatic 12-Position	The compass has a small Roll angle variation (<5°)	Provides the best calibration effect when	Pitch angle must be ≥45°.

Small-Tilt Calibration	during operation.	the Roll angle variation is <5°.	
Plane 12-Position Calibration	The compass only rotates on a horizontal plane, with Pitch and Roll angles <2°.	Provides the best calibration effect when the compass rotates within a plane.	During use, Pitch and Roll angles must be <2°.

Note: If the compass is fixedly installed on other equipment, the compass should be calibrated together with the equipment after installation. This allows the magnetic interference of the complete assembly to be collected, ensuring accurate compass measurements.

Product Dimension Drawing



Dimensions: L125 × W22 × H24 mm

Default Horizontal Installation: During installation, keep the sensor mounting surface parallel to the measured target surface. For installation methods, please refer to the rotation diagram. For other installation methods, refer to the "Product Installation Method" diagram and specify the required option when placing an order.

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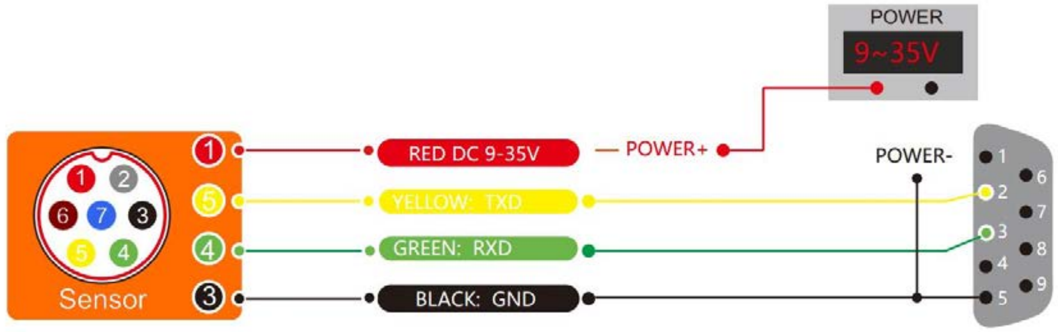
Product Electrical Connection

RS232 Wiring Definition

Line Color Function	RED	WHITE	BLACK	GREEN	YELLOW
	1	2	3	4	5
	VCC	NC	GND	RXD	TXD



RS485 Wiring Definition

Line Color Function	RED	WHITE	BLACK	GREEN	YELLOW
	1	2	3	4	5
	VCC	NC	GND	(B、D-)	(A、D+)

TTL Wiring Definition

Line Color Function	RED	WHITE	BLACK	GREEN	YELLOW
	1	2	3	4	5
	VCC	NC	GND	RXD	TXD

RS422 Wiring Definition

Line Color Function	RED	BLACK	GREEN	YELLOW	WHITE	BROWN
	1	2	3	4	5	6
	VCC	GND	RXD- (B-)	RXD+ (A+)	TXD+ (A+)	TXD- (B-)

4. Communication Protocol

1. Data Frame Format

(RTU Mode: 8 data bits, 1 stop bit, no parity, default baud rate: 9600)

Address Code	Function Code	Register Address		Register Quantity		CRC Check	
Address (1 byte)	Function (1 byte)	AddrH (1 byte)	AddrL (1 byte)	NumH (1 byte)	NumL (1 byte)	CRC16L (1 byte)	CRC16H (1 byte)
XX	0x03 Read 0x03 Write	XX	XX	XX	XX	XX	XX

Data Format: Hexadecimal

Address Code: Factory default: 0x01 (Users can configure the address as required, with a maximum value of 0xFF).

Function Code: 0x03: Read Holding Registers ;0x06: Preset Single Register.

Register Address: The starting address of the register to be read or written.

Register Quantity: The number of registers to be read or written.

CRC Check: The CRC check value is calculated based on the address code, function code, register starting address, register quantity, and CRC algorithm using a dedicated CRC16 calculation tool. (**Note:** When the address code, function code, or register starting address changes, the CRC check value will also change. When modifying the command, the corresponding CRC check value must be updated accordingly.)

Note: When using the Modbus serial port debugging assistant software to communicate with the sensor, it is not necessary to manually add the CRC check. However, a CRC check must be added when using a standard

serial port debugging assistant.

If the user needs to implement the CRC16 MODBUS calculation independently, the following C language program is provided for reference: unsigned short ModBusCRC(unsigned char *ptr, unsigned char size).

```
{
    unsigned short a,b,tmp,CRC16,V;
    CRC16=0xffff; // Initial value of CRC register
    for (a=0; a<size; a++) // N bytes
{
    CRC16=*ptr ^ CRC16;
    for (b=0;b< 8;b++) // 8-bit data
{
    tmp=CRC16 & 0x0001;
    CRC16=CRC16 >> 1; // Shift right by one bit
    if (tmp)
    CRC16=CRC16 ^ 0xa001; // XOR polynomial
}
     *ptr++;
}
    V = ((CRC16 & 0x00FF) << 8) | ((CRC16 & 0xFF00) >> 8); // Swap high and low bytes
    return V;
}
```

Example: The CRC check value of 01 06 00 0B 00 02 is 79 C9.

2. Command Format

2.1 Read PITCH Angle

Request Command: 01 03 00 01 00 01 D5 CA

Address Code	Function Code	Register Address		Register Quantity		CRC Check	
Address (1byte)	Function (1byte)	AddrH (1byte)	AddrL (1byte)	NumH (1byte)	NumL (1byte)	CRC16L (1byte)	CRC16H (1byte)
0x01	0x03	0x00	0x01	0x00	0x01	0xD5	0xCA

Response Command:

Address Code	Function Code	Byte Count	Register Data		CRC Check	
Address (1byte)	Function (1byte)	Byte Count (1byte)	DataH (1byte)	DataL (1byte)	CRC16L (1byte)	CRC16H (1byte)
0x01	0x03	0x02	XX	XX	XX	XX

Note: Example response frame: 01 03 02 4F 75 4D 93.The PITCH angle value is stored in the first two bytes of the register data field and is represented in hexadecimal format. When using a PLC or configuration software, the value can be directly read as a decimal number through a 16-bit register.The register data uses big-endian format, with the high byte transmitted first and the low byte transmitted second. The PITCH angle value can be calculated after converting the register data to a decimal value as follows:

Actual PITCH Angle = (Register Value - 20000) / 100.

If the register data is 4F 75, the decimal value is 20341,

Actual PITCH Angle = (20341 - 20000) / 100 = -3.41°.

2.2 Read ROLL Angle

Request Command: 01 03 00 02 00 01 25 CA

Address Code	Function Code	Register Address		Register Quantity		CRC Check	
Address (1byte)	Function (1byte)	AddrH (1byte)	AddrL (1byte)	NumH (1byte)	NumL (1byte)	CRC16L (1byte)	CRC16H (1byte)
0x01	0x03	0x00	0x02	0x00	0x01	0x25	0xCA

Response Command:

Address Code	Function Code	Byte Count	Register Data		CRC Check	
Address (1byte)	Function (1byte)	Byte Count (1byte)	DataH (1byte)	DataL (1byte)	CRC16L (1byte)	CRC16H (1byte)
0x01	0x03	0x02	XX	XX	XX	XX

Note: Example response frame: 01 03 02 4C 37 CD 52. The ROLL angle value is stored in the first two bytes of the register data field in hexadecimal format. When using a PLC or configuration software, the value can be directly read as a decimal number through a 16-bit register. The register data uses big-endian format, with the high byte transmitted first and the low byte transmitted second.

The actual ROLL angle can be calculated after converting the register data to a decimal value:

Actual ROLL Angle = (Register Value - 20000) / 100.

If the register data is 4C 37, the decimal value is 19511,

Actual ROLL Angle = (19511 - 20000) / 100 = -4.89°.

2.3 Read Heading Angle (Yaw Angle)

Request Command: 01 03 00 03 00 01 74 0A

Address Code	Function Code	Register Address		Register Quantity		CRC Check	
Address (1byte)	Function (1byte)	AddrH (1byte)	AddrL (1byte)	NumH (1byte)	NumL (1byte)	CRC16L (1byte)	CRC16H (1byte)
0x01	0x03	0x00	0x03	0x00	0x01	0x74	0x0A

Response Command:

Address Code	Function Code	Byte Count	Register Data		CRC Check	
Address (1byte)	Function (1byte)	Byte Count (1byte)	DataH (1byte)	DataL (1byte)	CRC16L (1byte)	CRC16H (1byte)
0x01	0x03	0x02	XX	XX	XX	XX

Note: Example response frame: 01 03 02 4F 75 4D 92. The Heading angle value is stored in the first two bytes of the register data field and is represented in hexadecimal format. (When using a PLC or configuration software, the data can be directly read as a decimal value through a 16-bit register.)The register data uses big-endian format, with the high byte transmitted first and the low byte transmitted second.

After converting the register data into a decimal value, the actual angle is calculated as follows:

Actual Heading Angle = (Register Value - 20000) / 100.

If the register data is 4F75, the decimal value is 20341,

Actual Heading Angle = (20341 - 20000) / 100 = 3.41°.

2.4 Read PITCH, ROLL, and Heading Angles

Request Command: 01 03 00 01 00 03 54 0B

Address Code	Function Code	Register Address		Register Quantity		CRC Check	
Address (1byte)	Function (1byte)	AddrH (1byte)	AddrL (1byte)	NumH (1byte)	NumL (1byte)	CRC16L (1byte)	CRC16H (1byte)
0x01	0x03	0x00	0x01	0x00	0x03	0x54	0x0B

Response Command:

Address Code	Function Code	Byte Count	Register Data			CRC Check	
Address (1byte)	Function (1byte)	Byte Count (1byte)	Pitch Angle (2byte)	Roll Angle (2byte)	Head Angle (2byte)	CRC16L (1byte)	CRC16H (1byte)
0x01	0x03	0x06	XXXX	XXXX	XXXX	XX	XX

Note: Example response frame: 01 03 06 4F 75 4C 37 4F 75 F0 08. The PITCH value is stored in the 1st–2nd bytes of the register data field, the ROLL value is stored in the 3rd–4th bytes, and the Heading value is stored in the 5th–6th bytes of the register data field. All values are represented in hexadecimal format.(When using a PLC or configuration software, the data can be directly read as decimal values through 16-bit registers.) The register data uses big-endian format, with the high byte transmitted first and the low byte transmitted second.

After converting the register data into decimal values, the actual angle values are calculated as follows:

Actual PITCH Angle = (Register Value - 20000) / 100

Actual ROLL Angle = (Register Value - 20000) / 100

Actual Heading Angle = (Register Value - 20000) / 100

If the register data field is 4F 75 4C 37 4F 75, the PITCH data is 4F 75, the ROLL data is 4C 37, and the Heading data is 4F 75. After conversion to decimal values, 4F 75 corresponds to 20341, 4C 37 corresponds to 19511, and 4F 75 corresponds to 20341.

Therefore, the actual angle values are calculated as follows:

Actual PITCH Angle = (20341 - 20000) / 100 = -3.41°,

Actual ROLL Angle = (19511 - 20000) / 100 = -4.89°,

Actual Heading Angle = (20341 - 20000) / 100 = -3.41°.

2.5 Set Communication Baud Rate

Request Command: 01 06 00 0C 00 04 48 0A

Address Code	Function Code	Register Address		Register Data		CRC Check	
Address (1byte)	Function (1byte)	AddrH (1byte)	AddrL (1byte)	DataH (1byte)	DataL (1byte)	CRC16L (1byte)	CRC16H (1byte)
0x01	0x06	0x00	0x0C	0x00	0x04	0x48	0x0A

Response Command:

Address Code	Function Code	Register Address		Register Data		CRC Check	
Address (1byte)	Function (1byte)	AddrH (1byte)	AddrL (1byte)	DataH (1byte)	DataL (1byte)	CRC16L (1byte)	CRC16H (1byte)
0x01	0x06	0x00	0x0C	0x00	0x04	0x48	0x0A

Note: Baud rate settings: 0x00: 2400 bps; 0x01: 4800 bps; 0x02: 9600 bps;

0x03: 19200 bps; 0x04: 115200 bps; 0x05: 14400 bps; 0x06: 38400 bps; 0x07: 57600 bps. The default baud rate is 0x02 (9600 bps). Other baud rates can be customized. After the baud rate is successfully changed, the device will send the response command at the original baud rate and then immediately switch to the new baud rate.

Remark: For high-frequency output applications, set the baud rate to 115200 bps.

2.6 Set Module Address

Request Command: 01 06 00 0D 00 02 99 C8

Address Code	Function Code	Register Address		Register Data		CRC Check	
Address (1byte)	Function (1byte)	AddrH (1byte)	AddrL (1byte)	DataH (1byte)	DataL (1byte)	CRC16L (1byte)	CRC16H (1byte)
0x01	0x06	0x00	0x0D	0x00	0x02	0x99	0xC8

Note: The default sensor address is 01.

Response Command:

Address Code	Function Code	Register Address		Register Data		CRC Check	
Address (1byte)	Function (1byte)	AddrH (1byte)	AddrL (1byte)	DataH (1byte)	DataL (1byte)	CRC16L (1byte)	CRC16H (1byte)
0x02	0x06	0x00	0x0D	0x00	0x02	0x99	0xFB

1. When multiple sensors are connected to the same bus (such as a MODBUS bus), each sensor must be configured with a different address to enable individual control and response.

2. After successfully changing the module address, all subsequent command frames and response data packets must use the new address code. Otherwise, the sensor will not respond to commands.

3. The module address (XX) can be set within the range of 00 to FE.

2.7 Query Module Address

Request Command: FF 03 00 0D 00 01 00 17

Address Code	Function Code	Register Address		Register Quantity		CRC Check	
Address (1byte)	Function (1byte)	AddrH (1byte)	AddrL (1byte)	NumH (1byte)	NumL (1byte)	CRC16L (1byte)	CRC16H (1byte)
0xFF	0x03	0x00	0x0D	0x00	0x01	0x00	0x17

Note: According to the Modbus protocol specification, the module address must be known before communication. Therefore, the address cannot normally be queried through the standard Modbus protocol. This product uses a customized protocol to query the Modbus address by using the address code FF. The address can also be queried when the current address code is known.

Response Command:

Address Code	Function Code	Byte Count	Register Data		CRC Check	
Address (1byte)	Function (1byte)	Byte Count (1byte)	DataH (1byte)	DataL (1byte)	CRC16L (1byte)	CRC16H (1byte)
0x01	0x03	0x02	XX	XX	XX	XX

2.8 Save Settings

Request Command: 01 06 00 0F 00 00 B9 C9

Address Code	Function Code	Register Address		Register Data		CRC Check	
Address (1byte)	Function (1byte)	AddrH (1byte)	AddrL (1byte)	DataH (1byte)	DataL (1byte)	CRC16L (1byte)	CRC16H (1byte)
0x01	0x06	0x00	0x0F	0x00	0x00	0xB9	0xC9

Response Command:

Address Code	Function Code	Register Address		Register Data		CRC Check	
Address (1byte)	Function (1byte)	AddrH (1byte)	AddrL (1byte)	DataH (1byte)	DataL (1byte)	CRC16L (1byte)	CRC16H (1byte)
0x01	0x06	0x00	0x0F	0x00	0x04	0xB9	0xC9

Note: For all parameter settings, if the Save Settings command is not sent after configuration, the modified settings will be lost after power-off.

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2.9 Restore Factory Settings

Request Command: 01 06 00 0E 00 00 E8 09

Address Code	Function Code	Register Address		Register Data		CRC Check	
Address (1byte)	Function (1byte)	AddrH (1byte)	AddrL (1byte)	DataH (1byte)	DataL (1byte)	CRC16L (1byte)	CRC16H (1byte)
0x01	0x06	0x00	0x0E	0x00	0x00	0xE8	0x09

Response Command:

Address Code	Function Code	Register Address		Register Data		CRC Check	
Address (1byte)	Function (1byte)	AddrH (1byte)	AddrL (1byte)	DataH (1byte)	DataL (1byte)	CRC16L (1byte)	CRC16H (1byte)
0x01	0x06	0x00	0x0E	0x00	0x00	0xE8	0x09

Note: The factory settings will take effect after the device is powered on again.

• The following protocol commands can be used to read and configure settings through a serial port debugging assistant or the ATO sensor host computer software.

2.10 Set Angle Mode

Request Command: 77 05 01 0C 00 12

Identifier	Data Length	Address Code	Command	Data Field	Checksum
(1byte)	(1byte)	(1byte)	(1byte)	(1byte)	(1byte)
0x77			0x0C	0x00: Request-Response Mode 0x01: 5Hz Data Rate 0x02: 15Hz Data Rate 0x03: 25Hz Data Rate 0x04: 35Hz Data Rate 0x05: 50Hz Data Rate	

Note: The default output mode is 00. If the device is configured in non-response mode, no data will be transmitted during the first 10 seconds after power-up or restart. After this 10-second idle period, the device will start continuously outputting data.

Response Command:

Identifier	Data Length	Address Code	Command	Data Field	Checksum
(1byte)	(1byte)	(1byte)	(1byte)	(1byte)	(1byte)
0x77			0x8C	0x00: Settings successful 0xFF: Settings failed	

Note: A 5 Hz data rate means that the device automatically outputs data 5 times per second. Other data rates follow the same principle. When using an RS485 interface, because RS485 operates in half-duplex mode, the device may not be able to receive input commands effectively while automatically transmitting data. In this case, commands may need to be sent repeatedly before the device can receive them successfully. Therefore, when **using an RS485 interface and requiring command interaction with the device, it is recommended to configure the device to operate in request-response mode.** Additionally, when the device is configured in automatic output mode, no data will be output during the first 10 seconds after power-on. During this period, the device can effectively receive external configuration commands.

2.11 Set Magnetic Declination

Request Command: 77 06 01 06 02 08 17

Identifier	Data Length	Address Code	Command	Data Field	Checksum
(1byte)	(1byte)	(1byte)	(1byte)	(1byte)	(1byte)
0x77			0x06	SXY.Y*	

Response Command:

Identifier	Data Length	Address Code	Command	Data Field	Checksum
(1byte)	(1byte)	(1byte)	(1byte)	(1byte)	(1byte)
0x77			0x86	SXY.Y*	

Note: S indicates the sign, where 0 represents positive and 1 represents negative. XX represents a two-digit integer, and Y represents one decimal place. For example, 0208 represents +20.8°.The checksum of this command is 16 (hexadecimal): 16 = 06 + 00 + 06 + 02 + 08. If the magnetic declination is set to -3.2°, the command should be: 77 06 01 06 10 32 4F, where: 4F = 06 + 00 + 06 + 10 + 32. Other magnetic declination values can be configured in the same way.

2.12 Read Magnetic Declination

Request Command: 77 04 01 07 0C

Identifier	Data Length	Address Code	Command	Data Field	Checksum
(1byte)	(1byte)	(1byte)	(1byte)	(1byte)	(1byte)
0x77			0x07		

Response Command:

Identifier	Data Length	Address Code	Command	Data Field	Checksum
(1byte)	(1byte)	(1byte)	(1byte)	(1byte)	(1byte)
0x77			0x87	SXY.Y*	

Note: The format of SXX.Y is the same as the magnetic declination setting format described in Section 2.3.

2.13 Start Calibration

Request Command: 77 04 01 08 0D

Identifier	Data Length	Address Code	Command	Data Field	Checksum
(1byte)	(1byte)	(1byte)	(1byte)	(1byte)	(1byte)
0x77			0x0C		

Response Command:

Identifier	Data Length	Address Code	Command	Data Field	Checksum
(1byte)	(1byte)	(1byte)	(1byte)	(1byte)	(1byte)
0x77			0x88	0x00: Settings successful 0xFF: Settings failed	

Note: This command is used to compensate for magnetic field deviations caused by the surrounding environment where the compass is installed. Each compass generally needs to perform calibration once when used in a new environment to reduce the influence of local magnetic interference on measurement accuracy. After calibration is completed, the Save Calibration command must be sent (see Section 2.6).

2.14 Save Calibration

Request Command: 77 04 01 09 0C

Identifier	Data Length	Address Code	Command	Data Field	Checksum
(1byte)	(1byte)	(1byte)	(1byte)	(1byte)	(1byte)
0x77			0x09		

Response Command:

Identifier	Data Length	Address Code	Command	Data Field	Checksum
(1byte)	(1byte)	(1byte)	(1byte)	(1byte)	(1byte)
0x77			0x89		

Note: The response frame returns the fitted calibration error obtained during the calibration process and the number of valid calibration points. The 5-byte data field consists of a 4-byte floating-point value representing the calibration error and a 1-byte integer value representing the number of valid calibration points. For example, in the response frame: 77 09 01 89 00 00 80 3F 0C EA,The data field is: 00 00 80 3F 0C,where 00 00 80 3F represents the floating-point value 1, and 0Crepresents 12 valid calibration points.

2.15 Stop Calibration

Request Command: 77 04 01 12 17

Identifier	Data Length	Address Code	Command	Data Field	Checksum
(1byte)	(1byte)	(1byte)	(1byte)	(1byte)	(1byte)
0x77			0x12		

Response Command:

Identifier	Data Length	Address Code	Command	Data Field	Checksum
(1byte)	(1byte)	(1byte)	(1byte)	(1byte)	(1byte)
0x77			0x72	0x00: Success 0xFF: Failed	

2.16 Clear Calibration Data

Request Command: 77 04 01 10 15

Identifier	Data Length	Address Code	Command	Data Field	Checksum
(1byte)	(1byte)	(1byte)	(1byte)	(1byte)	(1byte)
0x77			0x10		

Response Command:

Identifier	Data Length	Address Code	Command	Data Field	Checksum
(1byte)	(1byte)	(1byte)	(1byte)	(1byte)	(1byte)
0x77			0x90	0x00: Success 0xFF: Failed	