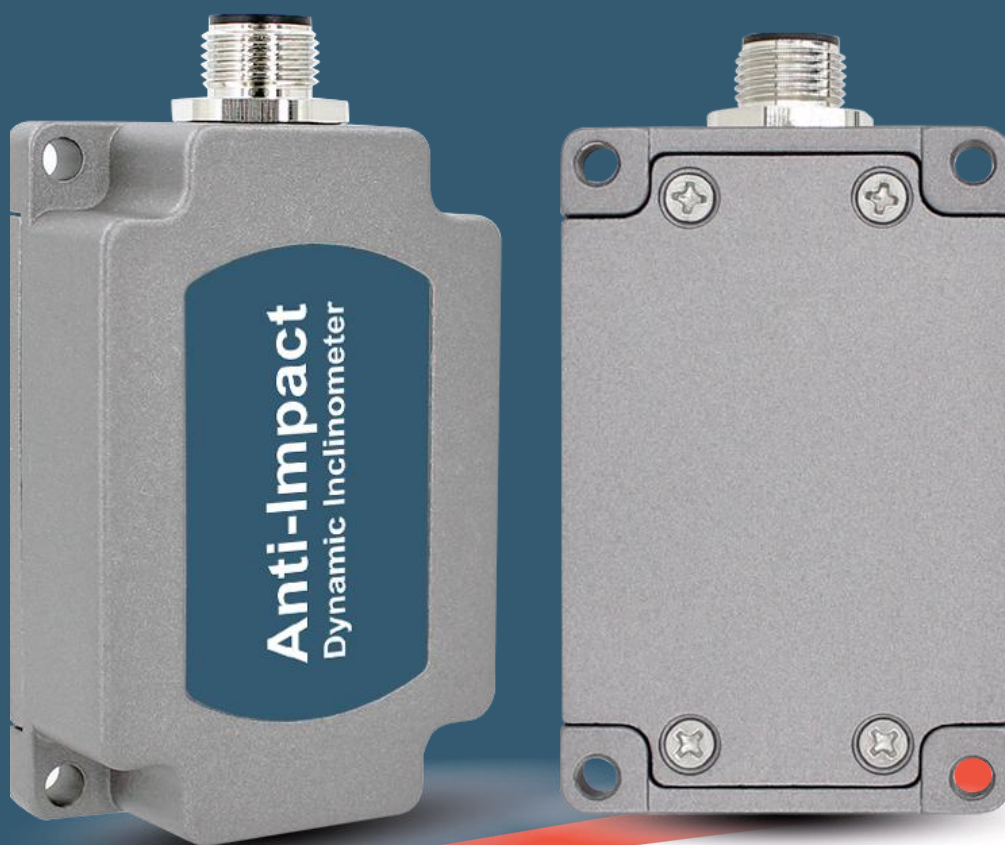




V1.5

DIGITAL OUTPUT DYNAMIC TILT SENSOR

HDA446T

Technical Manual

HDA446T DIGITAL OUTPUT DYNAMIC TILT SENSOR

○ Revision date: 2026-9-15

Note: Product functions, parameters, appearance, etc. will be adjusted as the technology upgrades. Please contact our pre-sales business to confirm when purchasing.

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HDA446T DIGITAL OUTPUT DYNAMIC TILT SENSOR



● PRODUCT DESCRIPTION

HDA446T A new generation of digital MEMS dynamic tilt sensor. It can measure the attitude parameters (roll, pitch, and azimuth) of a moving carrier, and suitable for tilt angle measurement under motion or vibration. HDA446T has a built-in high-precision acceleration and gyro sensor, and integrates the Kalman filter algorithm, which can measure the real-time motion data of the carrier under motion or vibration. The signal output modes such as RS485 / RS232 / TTL are optional, and the scalability is strong.

This product adopts non-contact measuring principle, which can output the current attitude and inclination in real time. It is simple to use and does not need to retrieve the relative changes of the two surfaces. Internally integrated high-precision AD and high-precision gyro units to compensate for non-linear, orthogonal coupling, temperature drift and centrifugal acceleration in real time; greatly eliminate centrifugal errors caused by motion acceleration interference, improve product dynamic measurement accuracy; adapt to long-term complex movements Work in places and harsh environments. The product is a dynamic and static dual-mode measurement sensor with strong resistance to external electromagnetic interference. It is suitable for all kinds of large-scale and high-strength shock and vibration industrial environments, and is an ideal choice for industrial automation control and measurement of attitude.

● MAIN FEATURES

- ★ Range (Roll angle $\pm 180^\circ$, pitch angle $\pm 90^\circ$, azimuth angle $\pm 180^\circ$)
- ★ Roll&Pitch Dynamic accuracy: $\pm 0.1^\circ$
- ★ RS485/232/TTL output Optional
- ★ Wide temperature operation $-40 \sim +85^\circ\text{C}$
- ★ Static accuracy: $\pm 0.05^\circ$
- ★ DC 9~36V wide voltage input
- ★ IP67/IP68 Protection level Optional

● APPLICATION FIELD

- ★ High vibration impact gravel equipment
- ★ Satellite communication vehicle attitude detection
- ★ Shield pipe jacking application
- ★ Underground drilling rig attitude navigation
- ★ Orientation measurement based on inclination angle
- ★ Various engineering machinery inclination measurement
- ★ Railway locomotive monitoring
- ★ Shield pipe jacking application
- ★ Geological equipment tilt monitoring
- ★ Ship navigation attitude measurement
- ★ Oil drilling equipment



HDA446T DIGITAL OUTPUT DYNAMIC TILT SENSOR

● SPECIFICATIONS

HDA446T		Condition	Parameter
Measure range		-	Roll $\pm 180^\circ$, pitch $\pm 90^\circ$, azimuth $\pm 180^\circ$ (initial value at power-down is 0°)
Measure axis		-	X axis / Y axis / Z axis
Roll&Pitch Static accuracy ¹⁾		@25 $^\circ\text{C}$	$\pm 0.05^\circ$
Roll&Pitch Dynamic accuracy(rms)		@25 $^\circ\text{C}$	$\pm 0.1^\circ$
Gyro	range	-	$\pm 300^\circ/\text{s}$
	Zero bias stability (10s Smooth)	-	$8.5^\circ/\text{h}$
	Angle random walk coefficient(Allan)	-	$0.25^\circ/\text{sqrt}(\text{h})$
Acceleration	range	-	$\pm 4\text{g}$ / $\pm 16\text{g}$ optional
	Bias stability(10s mean)	-	0.02mg
	Bias instability(Allan)	-	0.005mg
	Speed random walk coefficient(Allan)	-	$0.005\text{m/s}/\text{sqrt}(\text{h})$
Zero point temp. Coefficient ²⁾		-40 ~ 85 $^\circ\text{C}$	$\pm 0.01^\circ/\text{C}$
Sensitivity temp. Coefficient ³⁾		-40 ~ 85 $^\circ\text{C}$	$\leq 100\text{ppm}/^\circ\text{C}$
Power-on startup time			$\leq 3.5\text{S}$
Response time			0.01S
Output signal			RS485/RS232/TTL
Electromagnetic compatibility			According to EN61000 and GBT17626
MTBF			≥ 98000 hours / time
Insulation resistance			≥ 100 Megohm
Impact resistance			100g @ 11ms, 3 axial direction (half sinusoid)
Anti-vibration			10grms / 10 ~ 1000Hz
Waterproof level			Standard IP67, optional IP68 and corrosion-resistant IP68 protection level
Weight			$\leq 165\text{g}$ (Without cable)

1)Accuracy: refers to the root mean square difference between the measured and actual angle value by multiple measurements (>16 times) under normal temperature.

2)Zero temp. drift coefficient: the change rate of the indication value relative to normal temperature within the rated operating temperature range of the sensor at the zero degree.

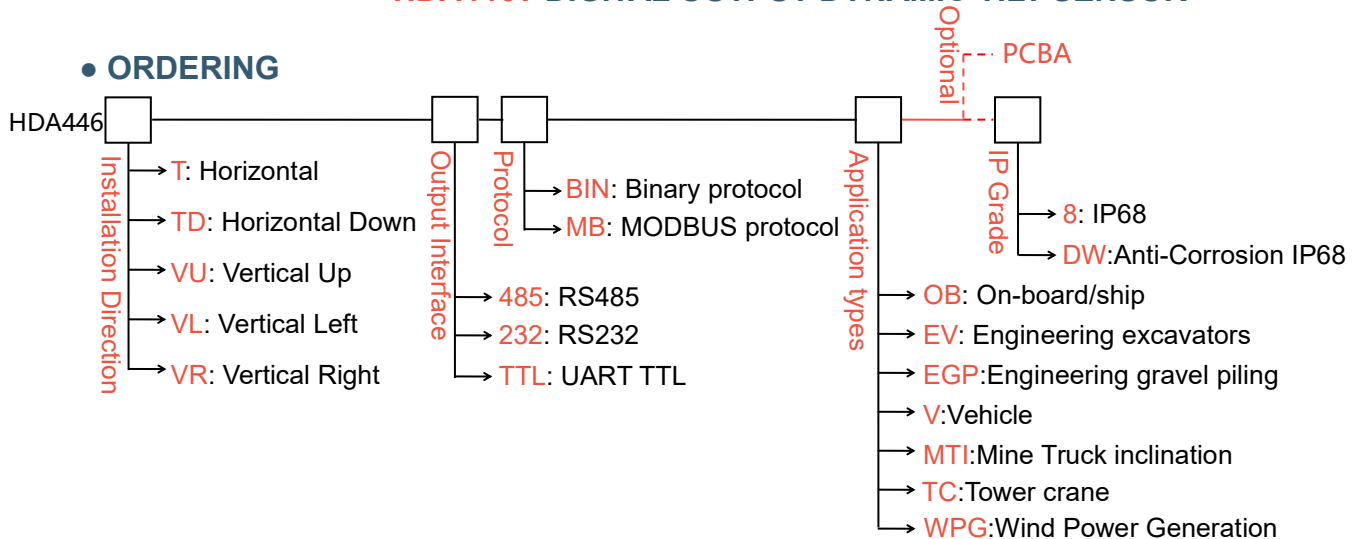
3)Sensitivity temp. drift coefficient: The percentage change rate with temperature of the full-scale indication relative to the full-scale indication at room temperature of the sensor in its rated operating temperature range.

● ELECTRICAL PARAMETERS

Parameter	Condition	Min	Typ		Max	Unit
Supply voltage	standard	9	12	24	36	V
Working current	without load		60mA(12V)			mA
Operating temp		-40			+85	$^\circ\text{C}$
storage temp		-40			+85	$^\circ\text{C}$

HDA446T DIGITAL OUTPUT DYNAMIC TILT SENSOR

• ORDERING



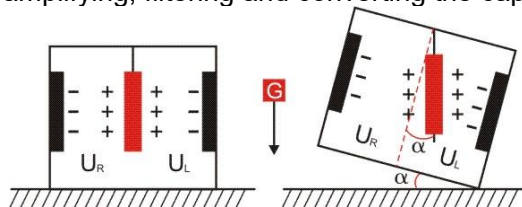
E.g: HDA446T-485-BIN-OB: Standard industrial scenario/horizontal installation/RS485 output interface/Binary protocol/ship application.

Note: 1. The default protection level of this product is IP67. If a higher protection level is required, for example: HDA446T-232-BIN-OB-8;

2. If only PCBA needs to be added after selection, for example: HDA446T-232-BIN-OB-PCBA.

• WORKING PRINCIPLE

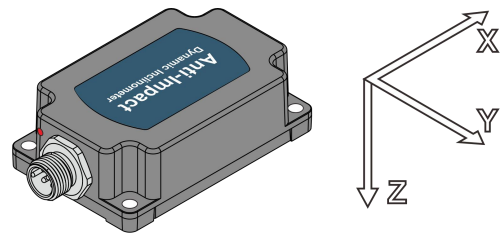
It adopts imported core control unit and uses the principle of capacitive miniature pendulum. According to the earth gravity principle, when the dip angle unit is inclined, the gravity of the earth can generate a gravity component on the corresponding pendulum, the corresponding capacitance can be changed, and the dip angle can be obtained by amplifying, filtering and converting the capacitance.



U_R , U_L are the voltage between the left and right pole plates of the pendulum and their corresponding electrodes, when the tilt sensor is tilted, U_R , U_L will change according to a certain rule, so $\int (U_R U_L)$ is a function on α of tilt angle: $\alpha = \int (U_R, U_L)$.

• INSTALLATION AXIAL

HDA446TT follows the NED coordinate system, right-handed. According to the rotation sequence of ZYX, when the positive direction of the X axis is directed to the front of the carrier, the rotation angle around the Z axis is the heading angle, the rotation angle around the Y axis is the pitch angle, and the rotation angle around the X axis is the roll angle.



• WORKING INDICATOR LIGHT DESCRIPTION

1. The working indicator light flashes after the product is powered on;
2. The working indicator light is on when the product has data to send.

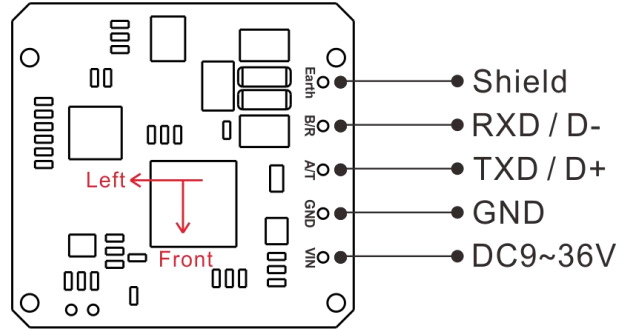
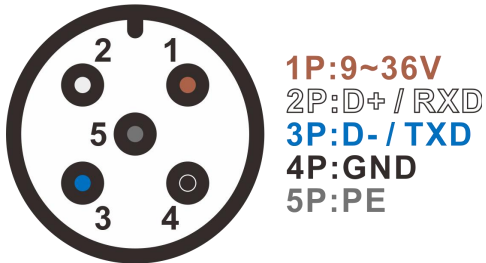
HDA446T DIGITAL OUTPUT DYNAMIC TILT SENSOR

• ELECTRICAL CONNECTIONS

FUNCTION PIN	1 PIN BROWN	2 PIN WHITE	3 PIN BLUE	4 PIN BLACK	5 PIN GRAY
	9~36V Power supply positive	RS485_D+/ RS232_RXD/ TTL_RXD	RS485_D-/ RS232_TXD/ TTL_TXD	GND Power supply negative	Shield

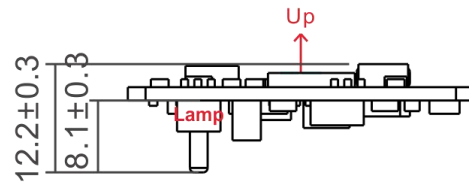
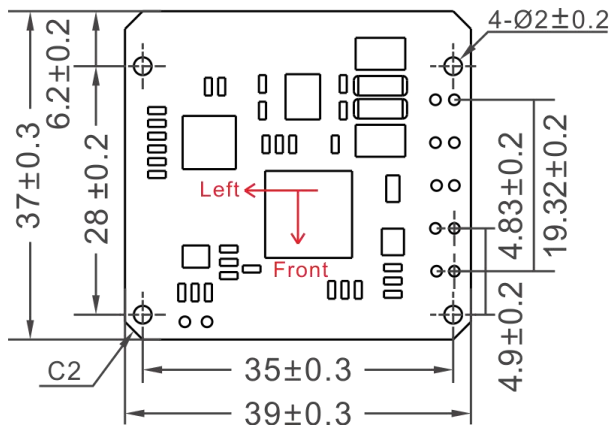
Definition diagram of M12 * 5P male connector pins

PCBA board wiring definition diagram



• SIZE

PCBA SIZE



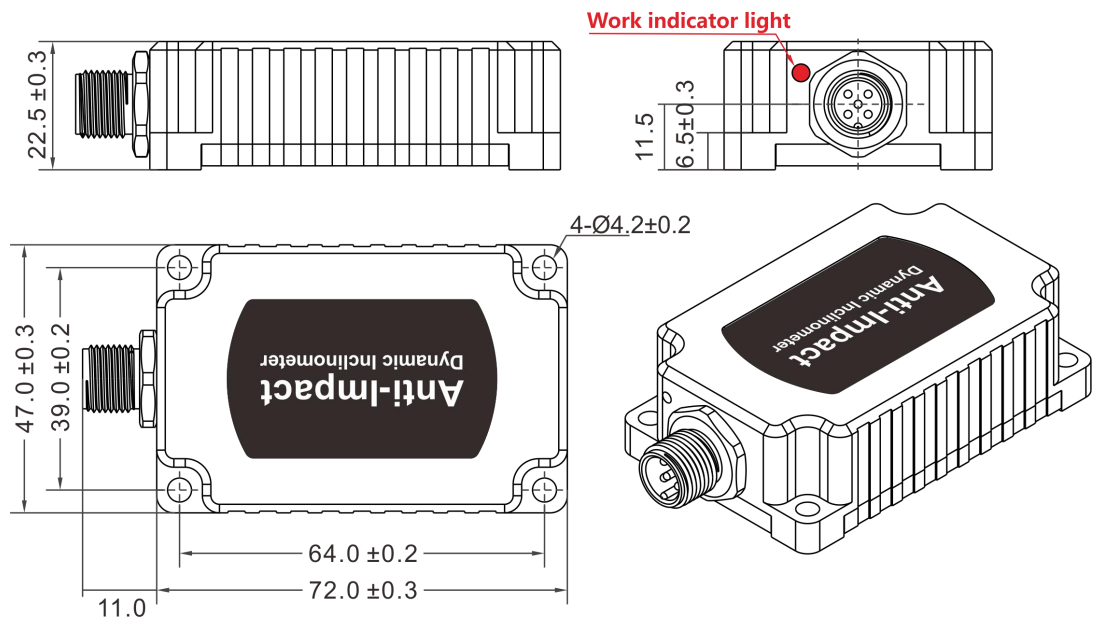
Shell size: L39xW37xH12.2mm

Installation size: L35xW28mm

Suggest using screws: 4 M2 screws

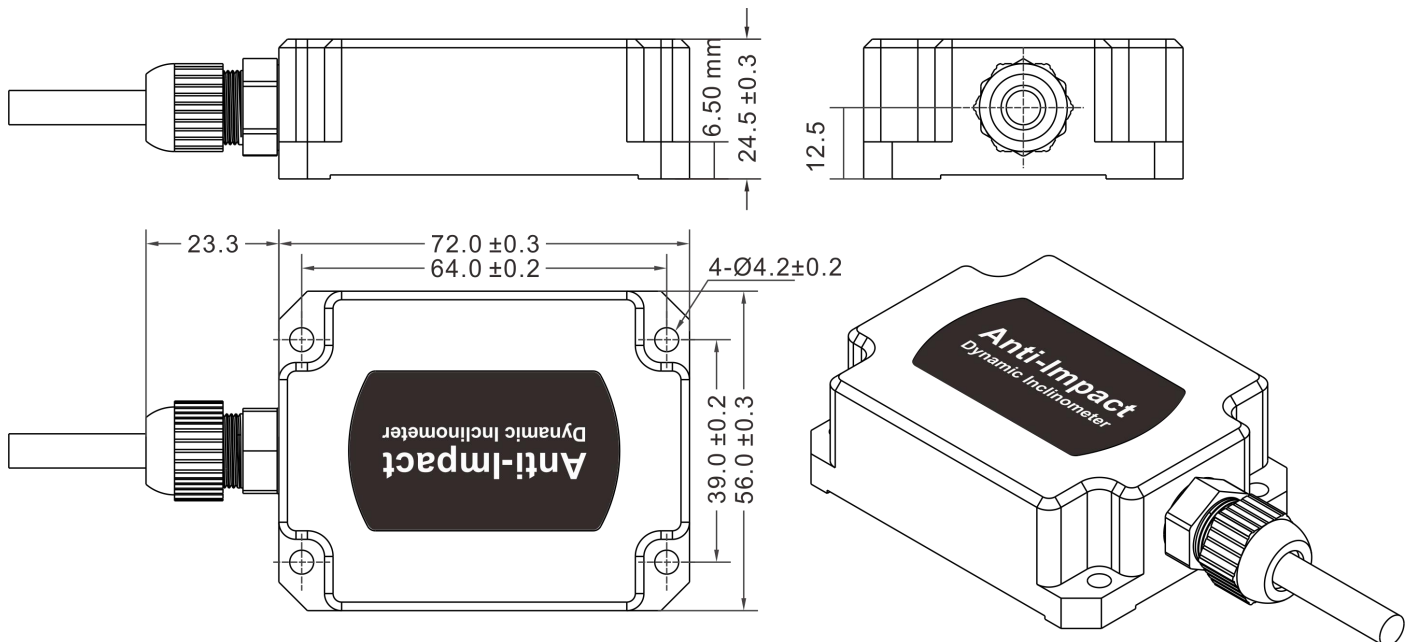
HDA446T DIGITAL OUTPUT DYNAMIC TILT SENSOR

SHELL SIZE



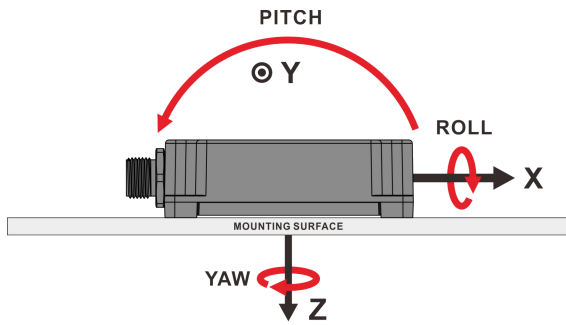
Shell size: 83 × 47 × 22.5mm
 Installation size: 64 × 39 × 6.5mm
 Suggest using screws: 4 M4 screws
 Shell material: aluminum alloy

Size of corrosion-resistant IP68 protection direct outlet product

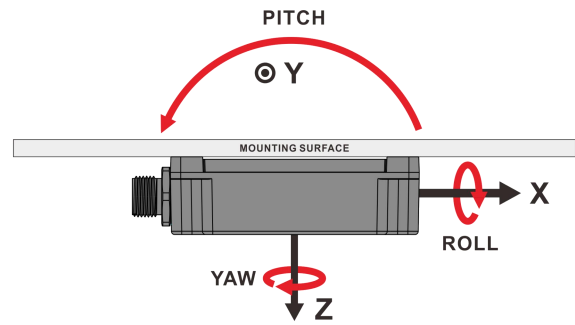


Shell size: 72 × 56 × 24.5mm
 Installation size: 64 × 39 × 6.5mm
 Suggest using screws: 4 M4 screws
 Shell material: 304 alloy steel

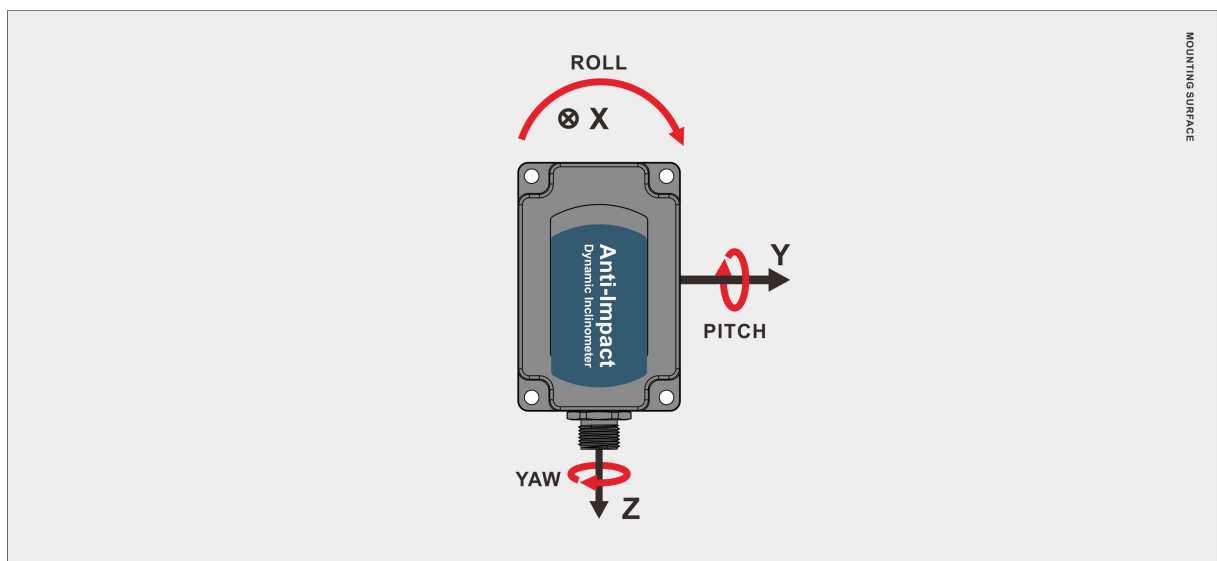
• **INSTALLATION METHOD**



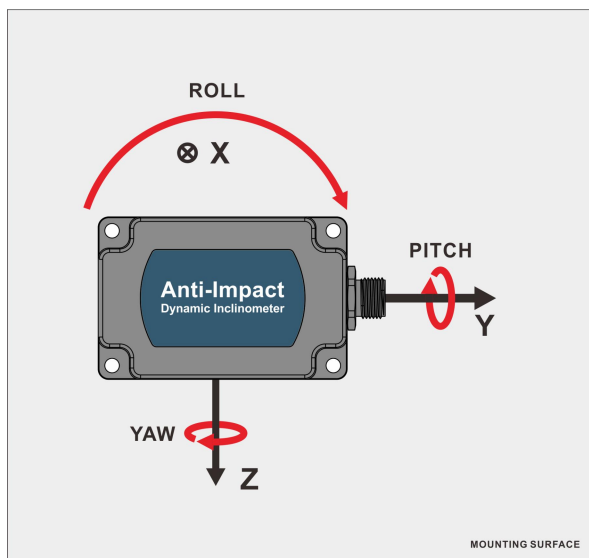
Horizontal Installation



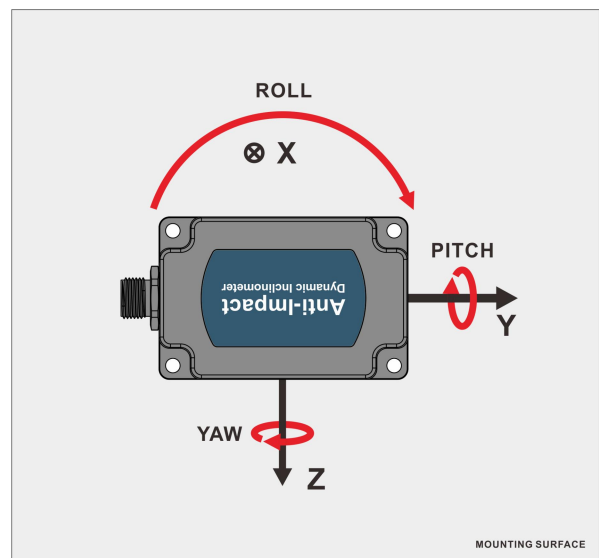
Horizontal-Down Installation



Vertical Installation



Vertical-Left Installation



Vertical-Right Installation

● BINARY PROTOCOL COMMUNICATION PROTOCOL**1.0 Communication Frame Format**

Field	Frame sync byte	Frame start byte	ADDR	CMD Command field	Length	Data Data field	CRC	Frame end byte
No. of bytes	1	1	1	1	2	0 to 504	2	1
Description	Sync. byte	Start of byte	Address	Command	Length of the Data	Data	CRC	End of Tx byte
Value	0xFF	0x02	0-FF	-	-	-	-	0x03

Notes:

A. The data length field includes the number of data fields (Data). MSB comes first, LSB comes after. A length of 0 indicates no data field. The longest data field is 504 bytes, and the longest frame byte is 512. Bytes.

B. The calculation of CRC starts from ADDR, including CMD, length field and data field, MSB first, LSB last, and calculate CRC according to the following function:

```
uint16 calcCRC(const uint8 *pBuffer, uint16 bufferSize)
{
    uint16 poly = 0x8408;
    uint16 crc = 0;
    uint8 carry;
    uint8 i_bits;
    uint16 j;

    for (j=0; j<bufferSize; j++)
    {
        crc = crc ^ pBuffer[j];
        for (i_bits=0; i_bits<8; i_bits++)
        {
            carry = crc & 1;
            crc = crc / 2;
            if (carry)
            {
                crc = crc^poly;
            }
        }
    }
    return crc;
}
```

1.1 Data Format And Endian

The data output of the device is in little-endian mode (such as integer and floating-point, with the low byte first and the high byte last).

1.2 Serial Port Default

The default baud rate of the serial port is 115200 bps, 1 start bit, 1 stop bit, no parity.

1.3 The default output is automatic output and the output frequency is 10Hz.

1.4 The default address is 0. The range is 0x00-0xFE, settable. 0xFF is a universal address.

2.0 Communication Mode

The sensor has two communication modes: query mode (question and answer mode) and continuous output mode (automatic data output at a certain frequency). Question and answer query operation can also be performed in continuous output mode.

2.1 Query Mode

In a question and answer mode, the user sends an inquiry or setting instruction to the sensor, and the device responds to the inquiry or setting instruction one-to-one. The device responds

to the query command in two formats: reply (CMD = ASK) and reply (CMD = RET). For details, refer to the command list in Chapter 4.

2.1.1 Response

The response frame format is as follows:

Field	Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
No. of bytes	1	1	1	1	1	1	1	1	1	1
Value	0xFF	0x02	0x00	IMU_ACK (0x01)	0x00	0x01	ERROR CODE	0xFF	0xFF	0x03

The response is a reply to the command. The execution status of the instruction is reflected by the error code. The following error code (ERROR CODE) determines the device's response to the query instruction. The following is a list of error codes;

IMU_Error Code	Value	Description
IMU_NO_ERROR	0x00	Command has been executed correctly
IMU_ERROR	0x01	Command did not execute correctly
IMU_INVALID_FRAME	0x04	Invalid command
IMU_INVALID_PARAMETER	0x09	Invalid parameter
IMU_NOT_READY	0x0A	Sensor is not ready

Note: The error code constitutes the data field (DATA) of the ACK frame.

2.1.2 Reply

The reply is a one-to-one response to the user command. The CMD and data fields of different query commands are different. Please refer to the command list in Chapter 4.

2.2 Continuous Output Mode

The continuous output mode is an automatic output mode. The selected data items are output at a certain frequency. The output frequency can be set.

3.0 Output Data Types

3.1 Output Data Types

By using output masks (uint32) to set the output data items and format, the user can choose the following data item output:

Valid mask	Description	sequence	support	Mask value
IMU_OUTPUT_EULER	Attitude angle	1	Support	0x00000001
IMU_OUTPUT_GYROSCOPES	Triaxial angular velocity after calibration	2	Support	0x00000002
IMU_OUTPUT_ACCELEROMETERS	Triaxial acceleration after calibration	3	Support	0x00000004

The order indicates the order of data output.

3.2 Data Output Format

3.2.1 Attitude angles Roll, Pitch and Yaw, expressed in real32 (float), 12 bytes, in radians.

Storage format:

Roll	Pitch	Yaw
------	-------	-----

3.2.2 Three-Axis Gyro Angular Rate Gx, Gy And Gz, Expressed In Real32 (Float), 12 Bytes, The Unit Is Rad.S⁻¹ (Radian / Second).

Storage format:

Gx	Gy	Gz
----	----	----

3.2.3 Three-Axis Acceleration Ax, Ay And Az, Expressed In Real32 (Float), 12 Bytes, The Unit Is m.S⁻².

Storage format:

Ax	Ay	Az
----	----	----

3.3 Output Data Order

According to different values of output masks (uint32), the corresponding output order will be generated. The default output masks (uint32) = 0x00000007 is as follows:

IMU_OUTPUT_EULER | IMU_OUTPUT_GYROSCOPES |

IMU_OUTPUT_ACCELEROMETERS (0x00000001 | 0x00000002 | 0x00000004) The

corresponding output data sequence and storage format are as follows:

Name	Roll	Pitch	Yaw	Gx	Gy	Gz	Ax	Ay	Az
Size (bytes)	4	4	4	4	4	4	4	4	4
	12			12			12		

The analysis of the data field is performed in the above storage format.

For example, output masks (uint32) = 0x00000001 is as follows:

IMU_OUTPUT_EULERS (0x00000001) corresponds to the output data sequence and storage format as follows:

Name	Roll	Pitch	Yaw
Size (bytes)	4	4	4
	12		

For example, output masks (uint32) = 0x00000005 is as follows:

IMU_OUTPUT_EULER | IMU_OUTPUT_ACCELEROMETERS (0x00000001 | 0x00000004), the corresponding output data sequence and storage format are as follows:

Name	Roll	Pitch	Yaw	Ax	Ay	Az
Size (bytes)	4	4	4	4	4	4
	12			12		

4.0 Command List

4.1 Set Automatic Output Data Items

* **IMU_SET_DEFAULT_OUTPUT_MASK----- (0x50)**

Function: Used to set the output MASK (output mask (uint32)), that is, the output data type (Buffer).

Note: It does not have the power-down save function. You must execute the save setting command to have the power-down save function.

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	5	1	1	1
0xFF	0x02	0x00	0x50	0x00	0x05	DATA	0xFF	0xFF	0x03

Of which: DATA part

DATA	
Reserved. Leave to 0 (bytes)	Default output mask (uint32)
1	4

Reply:

IMU_ACK

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1		1	1	1	1	1	1	1
0xFF	0x02	0x00	0x01	0x00	0x01	ERROR_CODE	0xFF	0xFF	0x03

4. 2 Get Data Items For Automatic Output

* IMU_GET_DEFAULT_OUTPUT_MASK----- (0x51)

Function: It is used to read the output MASK (output mask (uint32)) data item, which is used for data analysis.

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	0	1	1	1
0xFF	0x02	0x00	0x51	0x00	0x00	NULL	0xFF	0xFF	0x03

Reply: * IMU_RET_DEFAULT_OUTPUT_MASK ----- (0x52)

Role: Returns the output mask;

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	4	1	1	1
0xFF	0x02	0x00	0x52	0x00	0x04	DATA	0xFF	0xFF	0x03

Of which: DATA part

DATA
Default output mask(uint32)
4

4.3 Continuous Data Output

* IMU_CONTINUOUS_DEFAULT_OUTPUT ----- (0x90)

Function: Data items are continuously output.

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	See below	1	1	1
0xFF	0x02	0x00	0x90	0x00	0x24	See below	0xFF	0xFF	0x03

Data part is as follows (total length: 0x0024):

Name	Roll	Pitch	Yaw	Gx	Gy	Gz	Ax	Ay	Az
Size (bytes)	4	4	4	4	4	4	4	4	4
	12			12			12		

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Number Field	Real32	Float	Unit
Roll	BBFF0F9E	-0.007784	radian
Pitch	3C35E11F	0.011101	radian
Yaw	BD2E03F5	-0.042484	radian
Gx	B99D4848	-0.000300	Radians / second
Gy	3925ACF1	0.000158	Radians / second
Gz	389202DA	0.000070	Radians / second
Ax	3DE1E839	0.110306	m.S ⁻²
Ay	3D9D7DFA	0.076900	m.S ⁻²
Az	C11C1675	-9.755483	m.S ⁻²

4.4 Output Mode Setting

Output work mode

There are two modes of Mode, as follows:

IMU_QEURY_MODE (Query mold or Q & A mode): 0x00

IMU_CONTINUOUS_MODE (Continuous output mode): 0x01

The CONTINUOUS_MODE (continuous output mode) has different Divider values, corresponding to the following different output frequencies:

Divider	OUT(Hz)
0	INVALID
1	200
2	100
4	50
8	25
10	20
20	10
40	5
200	1

Note: The default is IMU_CONTLNIOUS_MODE (continuous output mode), and the frequency is 10Hz.

4.5 Set Output Mode Command

*** IMU_SET_CONTINUOUS_MODE-----(0x53)**

Function: Set the output mode;

Note: It does not have the power-down save function. You must execute the save setting command to save.

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	3	1	1	1
0xFF	0x02	0x00	0x53	0x00	0x03	As Follow	0xFF	0xFF	0x03

Of which: DATA part

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DATA		
Reserved.Leave to 0(bytes)	Mode	Divider
1	1	1
0	1	1

Note: Above Mode = 1, continuous output, Divider = 1, output frequency: 200Hz.

Reply:

IMU_ACK

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	1	1	1	1
0xFF	0x02	0x00	0x01	0x00	0x01	ERROR_CODE	0xFF	0xFF	0x03

4.6 Get Output Mode

* **IMU_GET_CONTINUOUS_MODE-----(0x54)**

Function: used to read the current mode;

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	0	1	1	1
0xFF	0x02	0x00	0x54	0x00	0x00	NULL	0xFF	0xFF	0x03

Reply:

* **IMU_RET_CONTINUOUS_MODE ----- (0x55)**

Function: Used to return Mode and Divider;

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	2	1	1	1
0xFF	0x02	0x00	0x55	0x00	0x02	DATA	0xFF	0xFF	0x03

Of which: DATA part

DATA	
Mode(uint8)	Divider(uint8)
1	1

4.7 Setting The Baud Rate

The baud rate is a 32-bit integer. The valid values are: 9600/19200/38400/57600/115200/256000.

* **IMU_SET_PROTOCOL_MODE-----(0x12)**

Function: Used to set the communication baud rate; (default is 115200)

Note: It does not have the power-down save function. You must execute the save setting command to save.

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The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	5	1	1	1
0xFF	0x02	0x00	0x12	0x00	0x05	As follow	0xFF	0xFF	0x03

Of which: DATA part

DATA	
Reserved.Leave to 0(bytes)	Baud rate(uint32)
1	4
0	115200

Note: Baud rate (uint32) is little-endian mode, with the low byte first and the high byte last.

Reply:

IMU_ACK

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	1	1	1	1
0xFF	0x02	0x00	0x01	0x00	0x01	ERROR_CODE	0xFF	0xFF	0x03

4.8 Get Baud Rate

* **IMU_GET_PROTOCOL_MODE-----(0x13)**

Function: Used to get the communication baud rate;

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	0	1	1	1
0xFF	0x02	0x00	0x13	0x00	0x00	NULL	0xFF	0xFF	0x03

Reply:

* **IMU_RET_PROTOCOL_MODE-----(0x14)**

Function: Return the current baud rate;

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	4	1	1	1
0xFF	0x02	0x00	0x14	0x00	0x04	DATA	0xFF	0xFF	0x03

Of which: DATA part

DATA
Baud rate
4

4.9 Setting the sensor address

The sensor address is the target address during communication. Only when the address field matches the address of the sensor can the communication succeed.

* **IMU_SET_ADDR-----(0x0F)**

Function: used to set the address of the sensor; (default is 0x00)

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Note: It doesn't have the power-down save function. You must execute the save setting command to save

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	1	1	1	1
0xFF	0x02	0x00	0x0F	0x00	0x01	address	0xFF	0xFF	0x03

Note: ADDR is the current sensor address to be changed, and DATA is the new sensor address to be set.

Reply:

IMU_ACK

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	1	1	1	1
0xFF	0x02	0x00	0x01	0x00	0x01	ERROR_CODE	0xFF	0xFF	0x03

Note: The reply ADDR is the previous sensor address.

4.10 Obtaining the Sensor Address

***IMU_GET_ADDR----- (0x0D)**

Function: used to obtain the sensor address;

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	0	1	1	1
0xFF	0x02	0x00	0x0D	0x00	0x00	NULL	0xFF	0xFF	0x03

Reply:

***IMU_RET_ADDR----- (0x0E)**

Function: return the sensor address;

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	1	1	1	1
0xFF	0x02	0x00	0x0E	0x00	0x01	ADDR	0xFF	0xFF	0x03

Of which: DATA part

DATA
ADDR
1

4.11 Setting The Measurement Installation Method(There are five installation methods: horizontal, horizontal down, vertical up, vertical left, and vertical right.)

***IMU_SET_FIXED_MODE----- (0x20)**

Function: used to set the installation method of the sensor; (default is 0x00, horizontal direction)

Note: It doesn't have the power-down save function. You must execute the save setting command to save

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The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	1	1	1	1
0xFF	0x02	0x00	0x20	0x00	0x01	Fixed_Mode	0xFF	0xFF	0x03

Note: Fixed_Mode: 0x00: Horizontal mode, 0x01: Vertical up, 0x02: Vertical left, 0x03: Vertical right, 0x04: Horizontal down.

Reply:

IMU_ACK

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	1	1	1	1
0xFF	0x02	0x00	0x01	0x00	0x01	ERROR_CODE	0xFF	0xFF	0x03

4.12 Get Sensor Address

*** IMU_GET_FIXED_MODE----- (0x21)**

Function: used to obtain the installation method of the sensor;

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	0	1	1	1
0xFF	0x02	0x00	0x21	0x00	0x00	NULL	0xFF	0xFF	0x03

Reply:

***IMU_RET_FIXED_MODE----- (0x22)**

Function: return the sensor address;

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	1	1	1	1
0xFF	0x02	0x00	0x22	0x00	0x01	Fixed_Mode	0xFF	0xFF	0x03

Of which: DATA part

DATA
Fixed_Mode
1

4.13 Set absolute/relative zero point

The zero point of the sensor is divided into absolute zero point and relative zero point; The reference plane for the output tilt angle of the absolute zero sensor is the geographic horizontal plane; When set as the relative zero point, the reference plane for the sensor output tilt angle is relative to the installation surface. When there is an error between the installation measurement surface of the sensor and the horizontal plane, the relative zero point can be set to reset the current angle (roll angle and pitch angle). At this time, the angle change output by the sensor is relative to the installation surface.

*** IMU_SET_OFFSET_MODE----- (0x25)**

Function: Used to set the zero point of the sensor; (Default is 0x00, absolute zero)

Attention: It does not have power failure saving function and requires executing the save setting command to have power failure saving function.

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The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	1	1	1	1
0xFF	0x02	0x00	0x25	0x00	0x01	Offset_Mode	0xFF	0xFF	0x03

Note: Offset_Mode: 0x00: Absolute zero point; 01: Relative zero point.

Reply: IMU_ACK

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	1	1	1	1
0xFF	0x02	0x00	0x01	0x00	0x01	ERROR_CODE	0xFF	0xFF	0x03

4.14 Obtain zero point type

* IMU_GET_OFFSET_MODE----- (0x26)

Function: Used to obtain the zero point type of the current sensor;

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	0	1	1	1
0xFF	0x02	0x00	0x26	0x00	0x00	NULL	0xFF	0xFF	0x03

reply:

*IMU_RET_OFFSET_MODE----- (0x27)

Function: Return the installation method of the sensor;

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	1	1	1	1
0xFF	0x02	0x00	0x27	0x00	0x01	OFFSET_Mode	0xFF	0xFF	0x03

Among them: DATA section

DATA
OFFSET_Mode
1

Offset_Mode: 0x00: Absolute zero point; 01: Relative zero point.

4.15 Set Gravity Magnitude

* IMU_SET_GRAVITY_MAGNITUDE----- (0xB1)

Function: set current gravity magnitude level;

Note: It does not have the power-down save function. You must execute the save setting command to save.

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	5	1	1	1
0xFF	0x02	0x00	0xB1	0x00	0x05	DATA	0xFF	0xFF	0x03

Of which: DATA part

DATA	
Reserved.Leave to 0(bytes)	magnitude(real32)
1	4

Magnitude: gravity magnitude level. Floating point type, little-endian mode.

Reply:

IMU_ACK

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	1	1	1	1
0xFF	0x02	0x00	0x01	0x00	0x01	ERROR_CODE	0xFF	0xFF	0x03

4.16 Get Gravity Magnitude

* **IMU_GET_GRAVITY_MAGNITUDE----- (0xB2)**

Function: get current gravity magnitude level;

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	0	1	1	1
0xFF	0x02	0x00	0xB2	0x00	0x00	NULL	0xFF	0xFF	0x03

Reply:

* **IMU_RET_GRAVITY_MAGNITUDE----- (0xB3)**

Function: return current gravity magnitude level;

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	4	1	1	1
0xFF	0x02	0x00	0xB3	0x00	0x04	DATA	0xFF	0xFF	0x03

Of which: DATA part

DATA
magnitude(real32)
4

4.17 Set Save Command

The set parameters do not have a power-down saving function. After changing the setting parameters, you must execute the setting save command to save the updated parameters.

* **IMU_SAVE_SETTINGS ----- (0x24)**

Function: It is used to save all the setting parameters to the EEPROM, and it has the function of power-down saving. No data fields. The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	0	1	1	1
0xFF	0x02	0x00	0x24	0x00	0x00	NULL	0xFF	0xFF	0x03

Reply:

IMU_ACK

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	1	1	1	1
0xFF	0x02	0x00	0x01	0x00	0x01	ERROR_CODE	0xXX	0xXX	0x03

Note: EEROR CODE refers to 6;

4.18 Default Data Query Command (When Output Mode Mode = 0, One Question And One Answer Mode)

* IMU_GET_DEFAULT_OUTPUT----- (0x56)

Function: Get the current default output data item..

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	0	1	1	1
0xFF	0x02	0x00	0x56	0x00	0x00	NULL	0xXX	0xXX	0x03

Reply:

*IMU_RET_DEFAULT_OUTPUT----- (0x57)

Function: Returns the default data item output.

When output mask = 0x00000007j for continuous automatic output, the Data part is as follows:

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	24	1	1	1
0xFF	0x02	0x00	0x57	0x00	0x24	See below	0xXX	0xXX	0x03

Data part as follow(total length: 0x0024):

Name	Roll	Pitch	Yaw	Gx	Gy	Gz	Ax	Ay	Az
Size (bytes)	4	4	4	4	4	4	4	4	4
	12			12			12		

4.19 Get the specified data item output

* IMU_GET_SPECIFIC_OUTPUT----- (0x58)

Function: Get the specially designated MASK data items.

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	4	1	1	1
0xFF	0x02	0x00	0x58	0x00	0x04	DATA	0xXX	0xXX	0x03

Of which: DATA part

DATA
Output masks(uint32)
4

The specified specified data items Output masks are any of the following specified data items:

IMU_OUTPUT_EULER | IMU_OUTPUT_GYROSCOPES |

IMU_OUTPUT_ACCELEROMETERS Any one or more combinations.

Reply:

*** IMU_RET_SPECIFIC_OUTPUT----- (0x59)**

Function: Returns the output of the specified data item.

The frame format is as follows:

Frame sync byte	Frame start byte	ADDR	CMD	LEN (MSB)	LEN (LSB)	DATA	CRC (MSB)	CRC (LSB)	Frame end byte
1	1	1	1	1	1	0x24	1	1	1
0xFF	0x02	0x00	0x59	0x00	0x24	DATA	0xFF	0xFF	0x03

DATA part as follow:(total length: 0x0024)

Name	Roll	Pitch	Yaw	Gx	Gy	Gz	Ax	Ay	Az
Size (bytes)	4	4	4	4	4	4	4	4	4
	12			12			12		

Output masks(uint32) = 0x00000007

IMU_OUTPUT_EULER|IMU_OUTPUT_GYROSCOPES|IMU_OUTPUT_ACCELEROMETER S.

● MODBUS COMMUNICATION PROTOCOL

1. Data frame format:

RTU Mode;Communication parameters:baud rate 9600 bps (Factory Default);

Data frame:1 start bit ,8 bit data, even check ,1 stop bit.

Note, please read the following items carefully before use:

1.Because the MODBUS protocol stipulates that the time between two data frames should be at least 3.5 bytes (for example, at a baud rate of 9600, the time is $3.5 \times (1/9600) \times 11 = 0.004s$). But in order to leave enough margin, this sensor increases this time to 5ms, so please leave at least 5ms time interval between each data frame.

The master sends the command--5ms idle--the slave responds to the command--5ms idle--the master sends the command.....

2.The MODBUS protocol stipulates the of the broadcast address --- 0 relevant content . This sensor can also accept the content of the broadcast address, but will not reply (except for the function of reading the address code). So broadcast address 0 can be used for the following purposes, for reference only.

①Set all the tilt sensor addresses of this model mounted on the bus to a certain address.

②Set all tilt sensors of this model mounted on the bus to relative/absolute zero.

③Test the sensor of this model on the entire bus, that is, the host sends a 0 address query angle command to the bus, and the communication indicator can flash, that is, the communication is normal.

3.In order to improve the reliability of the system, the three commands of setting the address command and setting the absolute/relative command, setting the baud rate, setting the output frequency and setting the parity bit must be sent twice in succession to be effective. "Send twice in a row" means that the two transmissions are successful (the slave has a reply each time), and the two questions-answers must be consecutive, that is, the host cannot insert other data frames in the middle of the two questions-answers, otherwise , This kind of command will be locked, the setting process is as follows:

Send the setting address command-Waiting for the successful setting command sent by the slave-(No other commands appear) Send the setting address command again-Waiting for the successful setting command sent by the slave-Successful modification

4.When the normal communication has accumulated to a certain number of times, the communication indicator will flash once.

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Standard MODBUS Data Register Address List:

Register address	Register Name	storage type	Byte count	storage type	Support function code
0x0002-0x0003	Phi Roll angle	Uint32	4	little-endian	0x03
0x0004-0x0005	Theta Pitch angle	Uint32	4	little-endian	0x03
0x0006-0x0007	azimuth angle	Uint32	4	little-endian	0x03
0x0008-0x0009	temperature	Uint16	2	little-endian	0x03

Note: The above registers support the reading and retrieval of single or multiple consecutive register addresses.

2. Read angle data:

MODBUS Functional code 03H

Host query command:		Slave response:		
Sensor address	01H	Sensor address	01H	
Functional code	03H	Functional code	03H	
Access register	00H	Data length 14 bytes	0EH	
First address	02H	Data byte 1 low 8 bits	C4H	Roll angle
Data length 4 bytes	00H	Data byte 1 high 8 bits	96H	
	07H	Data byte 2 low 8 bits	03H	
CRC	A5C8H	Data byte 2 high 8 bits	00H	
		Data byte 3 low 8 bits	F8H	Pitch angle
		Data byte 3 high 8 bits	9BH	
		Data byte 4 low 8 bits	01H	
		Data byte 4 high 8 bits	00H	
		Data byte 5 low 8 bits	6BH	Heading angle
		Data byte 5 high 8 bits	54H	
		Data byte 6 low 8 bits	02H	
		Data byte 6 high 8 bits	00H	
		Data byte 7 high 8 bits	03	Temperature
		Data byte 7 low 8 bits	06	
		CRC	C40CH	

Example 1 for reading measurement data commands:

Host sends			01H	03H	00H	02H	00H	07H	A5H	C8H
Slave reply										
01H	03H	0EH	C4H	96H	03H	00H	F8H	9BH	01H	
00H	6BH	54H	02H	00H	03H	06H	C4H	0CH		

Note: The data field of the slave reply frame is C4H, 96H, 03H, 00H, F8H, 9BH, 01H, 00H, 6BH, 54H, 02H, 00H, 03H, 06H.

The roll angle ($\pm 180^\circ$) is the 1-4th byte of the data field, the pitch angle ($\pm 90^\circ$) is the 5-8th byte of the data field, and the azimuth angle ($\pm 180^\circ$) It is 9-12 bytes, the low byte is first, the high byte is after, and the 13th-14th byte is the temperature. The angle is expressed by the number of points, a point corresponds to 0.001° , and $0.001 \times (\text{number of points} - \text{offset})$ is the angle. If

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the measurement range is $\pm 90^\circ$ and the offset is 90000, the total number of points is 180,000 points. So 0 corresponds to -90° , 180000 corresponds to $+90^\circ$, and 90000 corresponds to 0° . If the measurement range is $\pm 180^\circ$ and the offset is 180000, the total number of points is 360,000 points. So 0 corresponds to -180° , 180000 corresponds to 0° , and 360,000 corresponds to 180° .

Take the above data frame as an example: the angle conversion process is as follows:

- 1) Get the current angle points. Note that the low byte is first, the roll angle is 000396C4H, the pitch angle is 00019BF8H, and the azimuth angle is 0002546BH.
- 2) Converted to decimal, roll angle: 396C4H $\rightarrow$ 235204, pitch angle: 19BF8H $\rightarrow$ 105464, azimuth angle: 2546BH $\rightarrow$ 152683.
- 3) Roll angle minus offset 180000 (note: this value is a quantity related to the measurement range, the measurement range value is multiplied by 1000, if the offset of the measurement range $\pm 180^\circ$ is 180×1000 , then the measurement range is $\pm 90^\circ$ The offset is 90×1000), Roll angle: $235204 - 180000 = 55204$, pitch angle: $105464 - 90000 = 15464$, azimuth angle: $152683 - 180000 = -27317$.
- 4) Get the final angle, roll angle: $55204 \times 0.001 = 55.204^\circ$, pitch angle: $15464 \times 0.001 = 15.464^\circ$, azimuth angle: $-27317 \times 0.001 = -27.317^\circ$.

Temperature is the 13th-14th byte of the data field

Analysis:

The upper four bits of the 13th byte are sign bits, 0: positive temperature, 1: negative temperature, and the lower four bits are ten bits;

The high four bits of the 14th byte are the ones, and the low four bits are the tenths;

If the slave machine replies 03H, the temperature of 06H is 30.6°C .

3. Set sensor relative / absolute zero:

MODBUS Functional code 06H

Set relative/absolute zero command:		Slave response:	
Sensor address	01H	Sensor address	01H
Functional code	06H	Functional code	06H
Access register First address	00H	Register Address	00H
	10H		10H
If the byte is non-zero, it is relative zero, and if it is zero, it is absolute zero	00H	If the word is non-zero, it is relative zero, and if it is zero, it is absolute zero	00H
	FFH / 00H Relative/absolute		FFH / 00H Relative/absolute
CRC	C84FH / 880FH	CRC	C84FH / 880FH

Commands must be sent twice in a row to be effective, and there can be no other commands in between.

Examples of Set relative/absolute zero command:								
Host sends	01H	06H	00H	10H	00H	FFH	C8H	4FH
Slave reply	01H	06H	00H	10H	00H	FFH	C8H	4FH

Note: 0010 is the register address. This register controls whether the sensor output is relative zero or absolute zero. If it is non-zero (as in the above example, 00FFH is written), the output is a relative zero point. On the contrary, if it is zero (change the 5th and 6th bytes to 00H), it is an absolute zero. The last two bytes are the CRC checksum.

4. Set Sensor address:(Sensor address Factory default 1)

Set Sensor address Code Command:		Slave response:	
Sensor address	01H	Sensor address	01H
Functional code	06H	Functional code	06H
Register Address	00H	Register Address	00H
	11H		11H
New address of sensor	00 H	New address of sensor	00 H
	04H		04H
CRC	D80C	CRC	D80C

Commands must be sent twice in a row to be valid, and there can be no other commands in between.

Examples for Set Sensor address command application:

Host send	01 H	06 H	00 H	11 H	00 H	04H	D8H	0CH
Slave reply	01H	06H	00H	11H	00H	04H	D8H	0CH

Note: 0011H is the register address, which controls the Sensor address. In the above example, the address of the sensor has been changed to 0004H, and the last two bytes are the CRC checksum.

5. Set sensor baud rate :(factory default 9600 bps)

Set sensor baud rate command:		Slave response:	
Sensor address	01H	Sensor address	01H
Functional code	06H	Functional code	06H
Register Address	00H	Register Address	00H
	12H		12H
baud rate of sensors	00 H	baud rate of sensors	00 H
	XX		XX
CRC	CRC LH	CRC	CRC LH

XX: A0H:4800 A1H:9600 A2H:19200 A3H:38400 A4H:115200

Commands must be sent twice in a row to be valid, and there can be no other commands in between.

Examples for Set sensor baud rate command application:

Host send	01H	06H	00H	12H	00H	A2H	A8H	76H
Slave reply	01H	06H	00H	12H	00H	A2H	A8 H	76H

Note: 0012H is the Register Address, which controls the baud rate of the sensor. In the above example, set the baud rate of the sensor to 19200, and the last two bytes are the CRC checksum.

6. Read Sensor Address Code:

Read Sensor Address Code Command:		Slave response:	
Sensor address	00H	Sensor address	01H
Functional code	42H	Functional code	42H
Address	00H	Return Data length	02H
	11H		

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Data length	00 H		Sensor address			01H		
	01H					01H		
CRC	CRC LH		CRC			CRC LH		
Examples for Read Sensor Address command application:								
Host send	00 H	42 H	00 H	11 H	00 H	01H	E9H	D1H
Slave reply	01H	42H	02H	01H	01H	6CH	28H	

7. Set Sensor communication character format :(factory default even check)

Set Sensor communication character format Command:		Slave response:	
Sensor address	01H	Sensor address	01H
Functional code	06H	Functional code	06H
Register Address	00H	Register Address	00H
	09H		09H
New format for sensors	00H	New format for sensors	00H
	00H		00H
CRC	59C8	CRC	59C8

Note: The command must be sent twice in a row to be effective, and there can be no other commands between the two, and it is effective after power-on again.

Examples for Set Sensor communication character format Command Application:								
Host send	01H	06H	00H	09H	00 H	00H	59H	C8H
Slave reply	01H	06H	00H	09H	00H	00H	59H	C8H

The above example is to set the byte format to: a start bit + 8 data bits, no parity, +1 stop bit
It is effective after power on again. The factory default is a start bit + 8 data bits, even parity +1 stop bit.

Note: 0009 is Register Address, which controls the character format of sensor communication.

0000H: One start bit + 8 data bits No parity + 1 stop bit.

0001H: One start bit + 8 data bits, odd parity check + 1 stop bit.

0002H: One start bit + 8 data bits, even parity +1 stop bit.

8. Set automatic output frequency of sensor:(Factory default 0 Hz, query mode)

Set automatic output frequency of sensor Command:		Slave response:	
Sensor address	01H	Sensor address	01H
Functional code	06H	Functional code	06H
Register Address	00H	Register Address	00H
	13H		09H
The output frequency of the sensor	00H	The output frequency of the sensor	00H
	XXH		XXH
CRC	CRC LH	CRC	CRC LH

XXH:00H:0Hz(Query Mode)

01H: 5Hz, 02H: 10Hz, 03H: 20Hz, 04H: 25Hz, 05H: 50Hz, 06H: 100Hz.

Note: commands must be sent twice in a row to be valid, and there can be no other commands in between.

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Set automatic output frequency of sensor Command Example :

Host send	01 H	06 H	00 H	13 H	00 H	04H	79H	CCH
Slave reply	01H	06H	00H	13H	00H	04H	79 H	CCH

The above example is to Set the byte format: the automatic output frequency is :25 Hz.

9. Sensor heading angle clear command:

Sensor heading angle clear command:		Slave response:	
Sensor address	01H	Sensor address	01H
Functional code	06H	Functional code	06H
Register Address	00H	Register Address	00H
	15H		15H
Sensor clear command	00H	Sensor clear command	00H
	FFH		FFH
CRC	D8 4E	CRC	D8 4E

Sensor heading angle clear Command Example :

Host send	01 H	06 H	00 H	15 H	00 H	FFH	D8H	4EH
Slave reply	01 H	06 H	00 H	15 H	00 H	FFH	D8H	4EH

The above example is to clear the current heading angle to zero.

10. Software reset:

Sensor Software reset command:		Slave response:	
Sensor address	01H	Sensor address	01H
Functional code	06H	Functional code	06H
Register Address	00H	Register Address	00H
	0EH		0EH
Sensor clear command	00H	Sensor clear command	00H
	FFH		FFH
CRC	A8 49	CRC	A8 49

Sensor Software reset Command Example :

Host send	01H	06H	00H	0EH	00H	FFH	A8H	49H
Slave reply	01H	06H	00H	0EH	00H	FFH	A8H	49H

The above example is to Software reset.