



Tactical Grade MEMS

FSS-IMU16488 Product Sheet

10-DOF Inertial Sensors

FSS-IMU16488_Datasheet

Features

Tactical Grade MEMS Gyroscope

- Bias Instability: 0.8°/hr
- Angle Random Walk: 0.1°/√hr
- Temperature Drift: 0.08°/s (-40 ~ 85°C, ≤1°C/min @1σ)

Tactical Grade MEMS Accelerometer

- Bias Instability: 10μg
- Velocity Random Walk: 0.0
- Temperature Drift: 1mg (-40 ~ 85°C, ≤1°C/min @1σ)

Refined temperature compensation

- Wide Temperature Range: -40°C ~ 85°C
- Precise Temperature Calibration

Independent Rotary Table Calibration

- Each module is calibrated separately in terms of sensitivity, bias instability, and misalignment

High-intensity Tolerance

- Ultra Shock Resistance: 2000g (0.5ms, Half-sine shock pulse, 3-axis)
- Superb Vibration Resistance: 10g (10~2KHz, 3-axis)
- Ultra-wide Operating Temperature Range: -40°C ~ 85°C

Benefits

- Real-time and Flexibility: Configurable output sampling rate up to 200Hz
- Digital Interfaces: Serial ports, and SPI interface
- Small Size and Low Weight: 47*44*14mm, about 32.2g

Description

FSS-IMU16488 is a 10-axis MEMS inertial measurement unit (IMU) module developed by Forsense (Shanghai) Technology Co., Ltd. It consists of a 3-axis gyroscope, a 3-axis accelerometer, a 3-axis magnetometer, and a barometer. **High precision and high resolution** combine to help capture subtle vibration and tilt. **A large number of output parameters** enable the perception of motion despite intense shaking. All IMU modules are **calibrated independently on a rotary table** and **adjusted precisely over an ultra-wide temperature range in a temperature chamber** before leaving the factory, so that they can deliver stable and consistent performance in most extreme conditions.

Applications

- Autonomous Driving: Passenger vehicles, Robots, engineering vehicles, and underwater vehicles
- Stabilized Platforms: Pan tilt and satellite communication on the move
- Navigation Control: Autopilot systems, and fixed-wing drones

Apart from standard performance and output parameters, Forsense also provides **customized services, including software development and LOGO design**, to better your products!



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1. Performance Parameters

1.1 Gyroscope Key Metrics

Table1 Gyroscope Key Metrics

Parameters	Test Conditions/Remarks	Min.	Typ.	Max.	Unit
Measurement Range			±500		°/s
Bias Instability X-axis ¹	@25°C, ALLAN Variance, 1σ		1.0		°/hr
Bias Instability Y-axis ¹			0.8		°/hr
Bias Instability Z-axis ¹			0.8		°/hr
Misalignment			0.02		deg
Internal Low-pass Cutoff Frequency	Adjustable software		47		Hz
ODR			200		Hz
Measure Delay			7		ms
Offset Error over Temperature ²	-40°C ~ 85°C, ≤1°C/min @1σ		0.08		°/s
Random Walk X-axis ²	@25°C, ALLAN Variance, 1σ		0.15		°/√hr
Random Walk Y-axis			0.1		°/√hr
Random Walk Z-axis			0.1		°/√hr
Scale Coefficient Error			1.5		‰
Scale Factor Nonlinear			200		ppm

Note 1: IEEE standard values acquired from Allan Variance analysis in a static environment (25°C)

Note 2: 1σ variation of full-temperature bias at a heating rate of 1°C/min

1.2 Accelerometer Key Metrics

Table2 Accelerometer Key Metrics

Parameters	Test Conditions/Remarks	Min.	Typ.	Max.	Unit
Measurement Range			±6		g
Bias instability ¹	@25°C, ALLAN Variance, 1σ		10		μg
Misalignment			0.02		deg
Internal Low-pass Cutoff Frequency	Adjustable Software		47		Hz
ODR			200		Hz
Measure Delay			7		ms
Offset Error over Temperature ²	-40°C~85°C, ≤1°C/min @1σ		XY:1.0 Z:2		mg
Random Walk X-axis	@25°C, ALLAN Variance, 1σ		0.015		m/s/√hr
Random Walk Y-axis			0.015		m/s/√hr
Random Walk Z-axis			0.02		m/s/√hr

Note 1: IEEE standard values acquired from Allan Variance analysis in a static environment (25°C)

Note 2: 1σ variation of full-temperature bias at a heating rate of 1°C/min

Fig. 1 Gyroscope - Allan Variance Curve

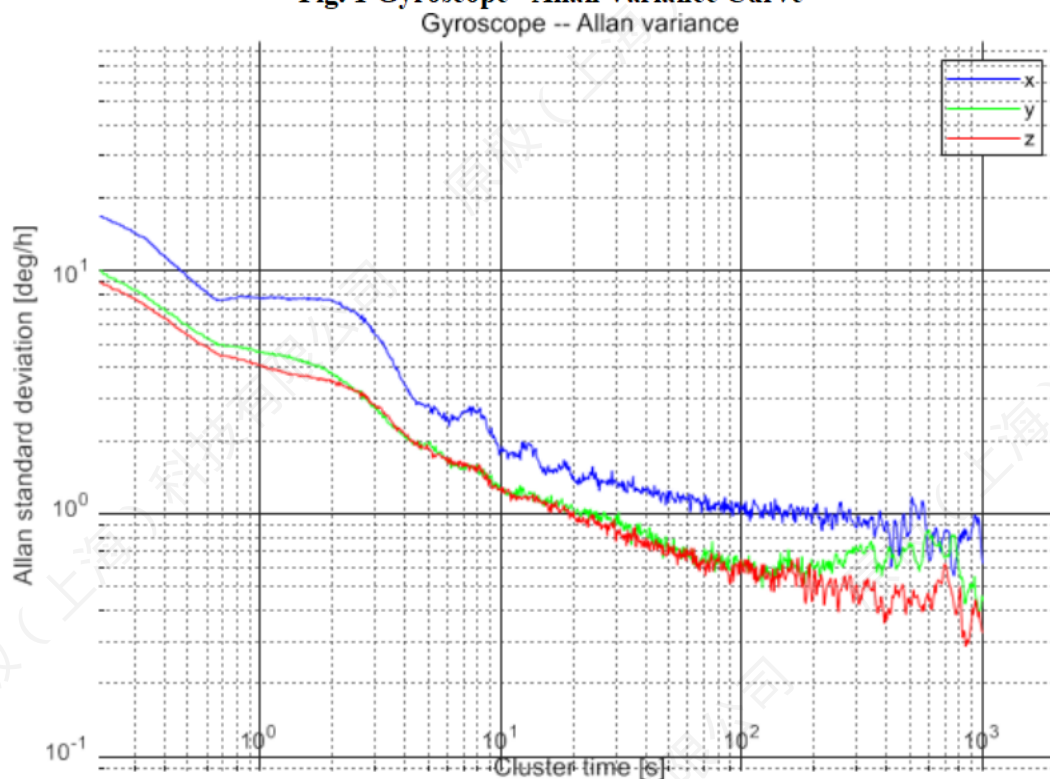
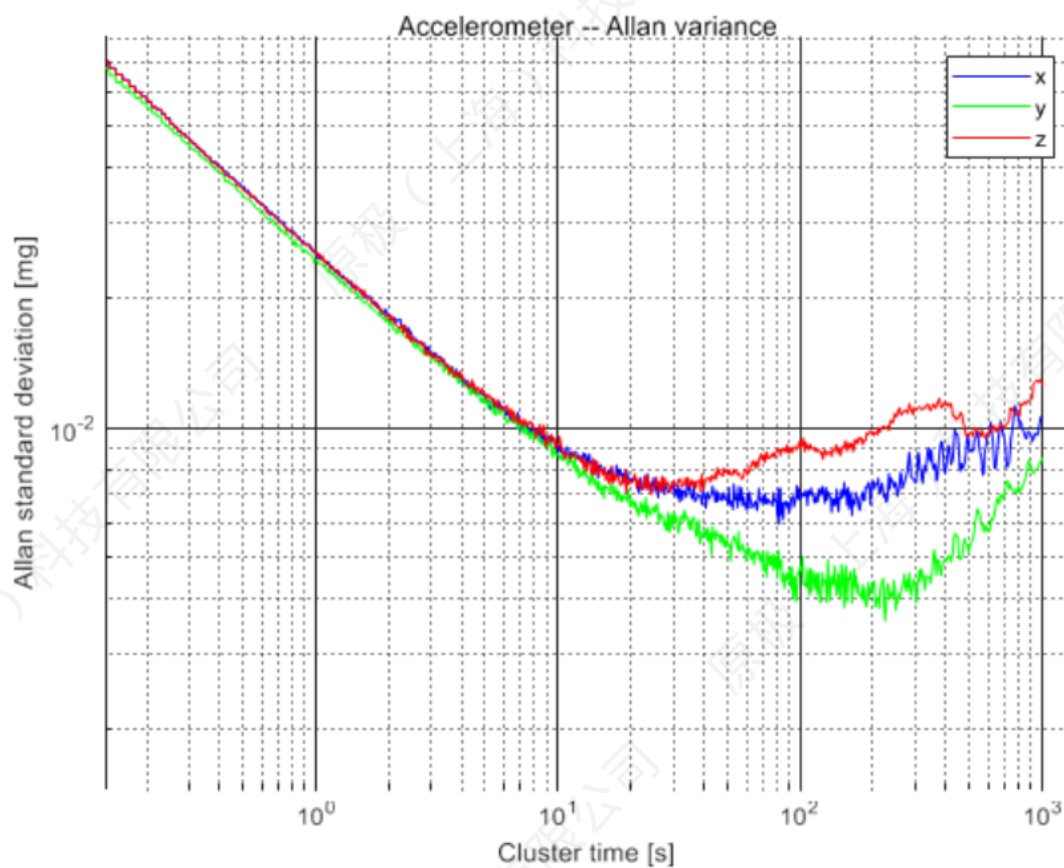
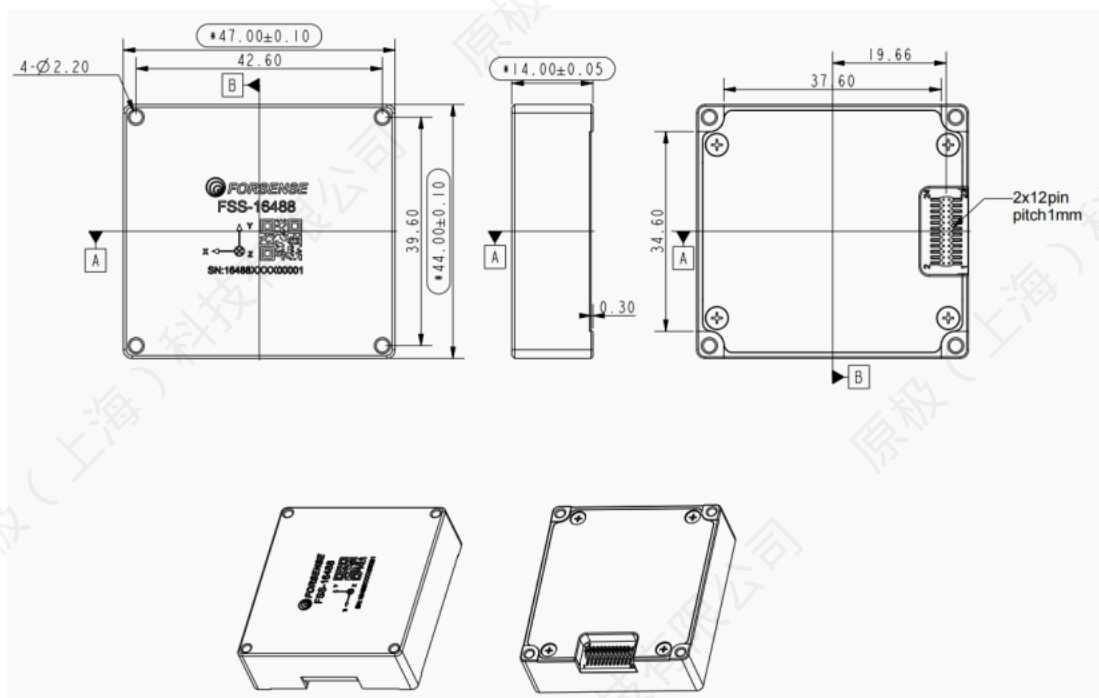


Fig. 2 Accelerometer - Allan Variance Curve



2. External Structure

Fig. 3 Outline Structure and Dimensions (unit: mm)



3. Electrical Properties

3.1 Absolute Maximum Ratings

Table 3 Absolute Maximum Ratings

Parameters	Symbol	Rating	Unit
Voltage for Circuit to Circuit	VCC	-0.3 to 4	V
Ground	GND	-	-
Input Pin Voltage	Vin	-0.3 to VCC+0.2	V
Operating Temperature	Tot	-40 to 85	°C
Storage Temperature	Tstg	-40 to 85	°C

3.2 Operating Conditions

Table 4 Operating Conditions

Parameters	Symbol	Min.	Typ.	Max.	Unit
Voltage for Circuit to Circuit	VCC	3.0	3.3	3.4	V
VCC Maximum Ripple	Vrpp		±40		mV
Power Consumption	P	1.09		1.25	W
Operating Temperature	Tot	-40		85	°C
Storage Temperature	Tstg	-40		85	°C

3.3 IO Threshold Characteristics

Table 5 IO Threshold Characteristics

Parameters	Symbol	Min.	Typ.	Max.	Unit
Input Pin Low Voltage	Vin_low	0		VCC*0.2	V
Input Pin High Voltage	Vin_high	VCC*0.7		VCC+0.2	V
Output Pin Low Voltage	Vout_low	0		0.45	V
Output Pin High Voltage	Vout_high	VCC-0.45		VCC	V

4. Description

Fig. 4 Pin Diagram

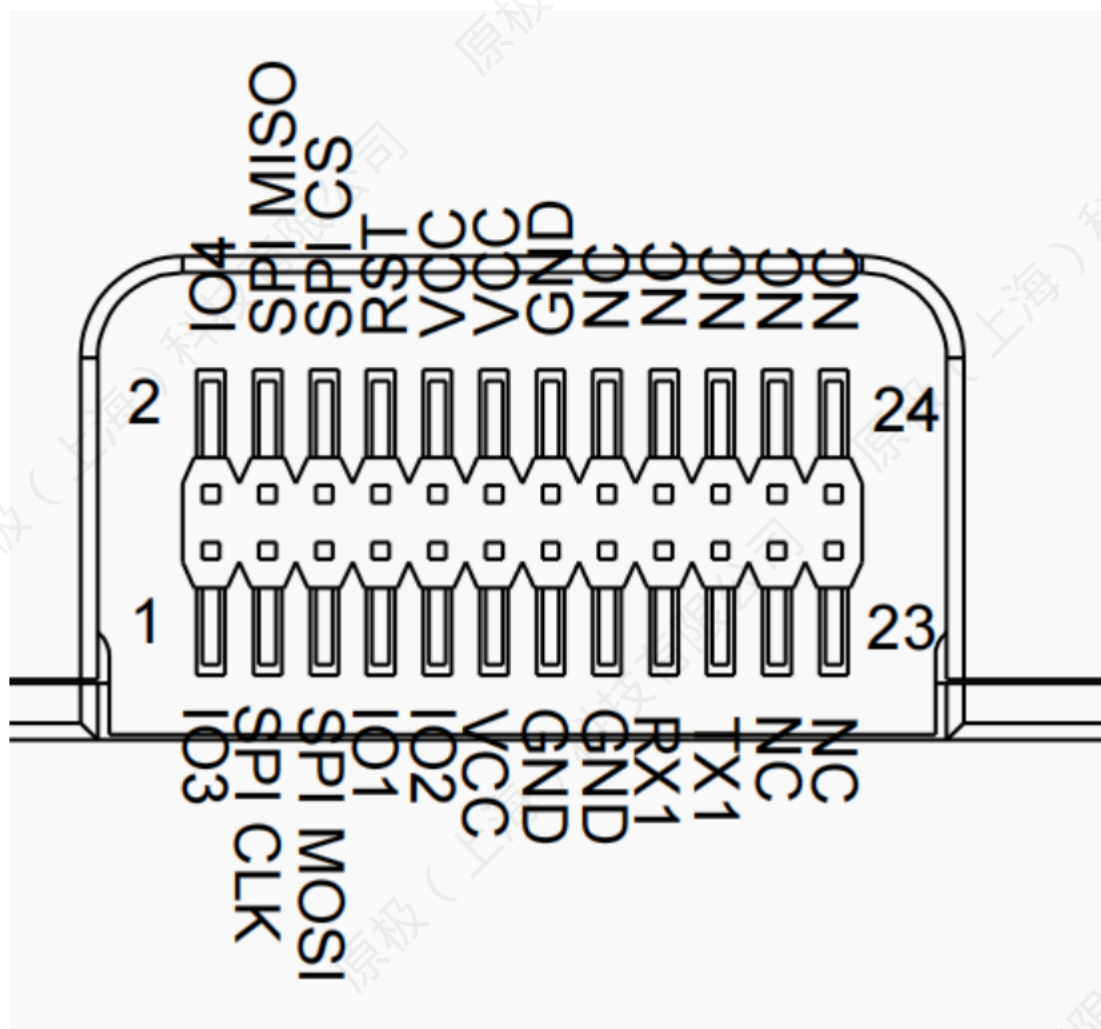


Table 6 Pin Function

Pin No.	Name	Type	Function
1	IO3	I/O	Configurable Digital Input/Output
2	IO4	I/O	Configurable Digital Input/Output
3	SPI_CLK	I	SPI Serial Clock
4	SPI_MISO	O	SPI MISO
5	SPI_MOSI	I	SPI MOSI

6	CS	I/O	SPI Chip Select
7	IO1	I/O	Configurable Digital Input/Output
8	RST	I	External hardware reset input
9	IO2	I/O	Configurable Digital Input/Output
10,11,12	VCC	S	Power input (+3.3V)
13,14,15	GND	S	Ground
17	RX1	O	Serial ports receive asynchronous data input (Data communication interface (LVTTTL))
19	TX1	I	Serial ports receive asynchronous data output (Data communication interface (LVTTTL))
16,18,20、 21、 22、 23、 24	NC	/	No connection

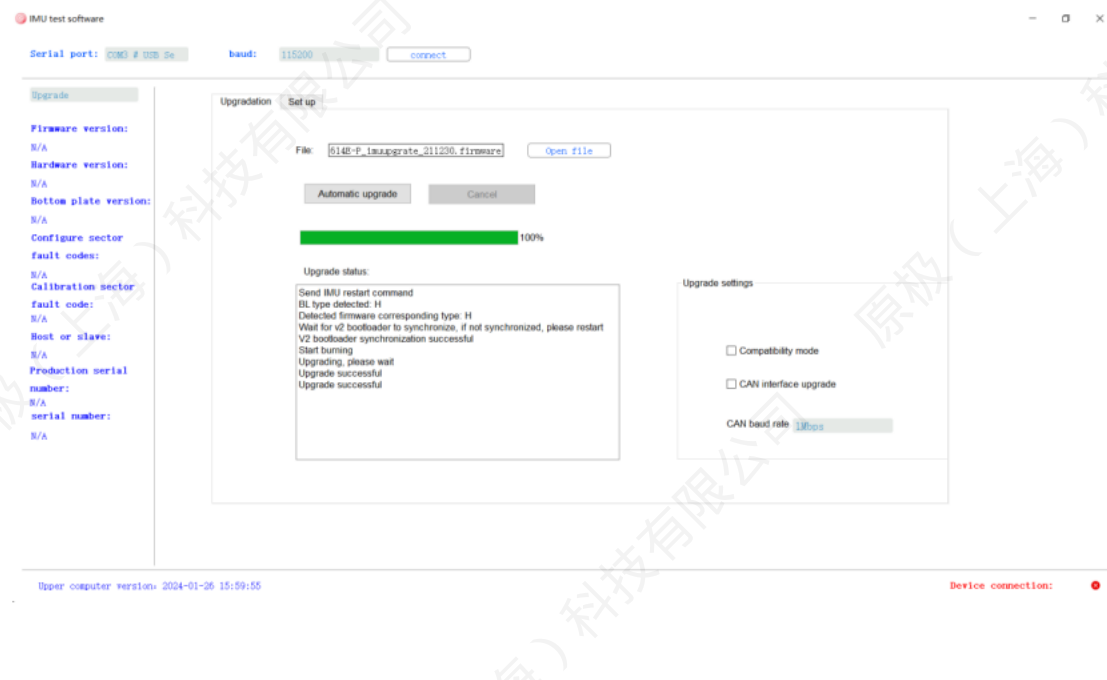
Note 1: Pin Type: I: input, O: output, S: power supply, NC: not connected.

Note 2: IMU hardware needs to be reset by triggering /RST before the master initialization.

5. Serial Port Firmware Upgrade

Use the FSS IMUs to test the PC software - Select firmware upgrade - Open the firmware - Click Auto Upgrade.

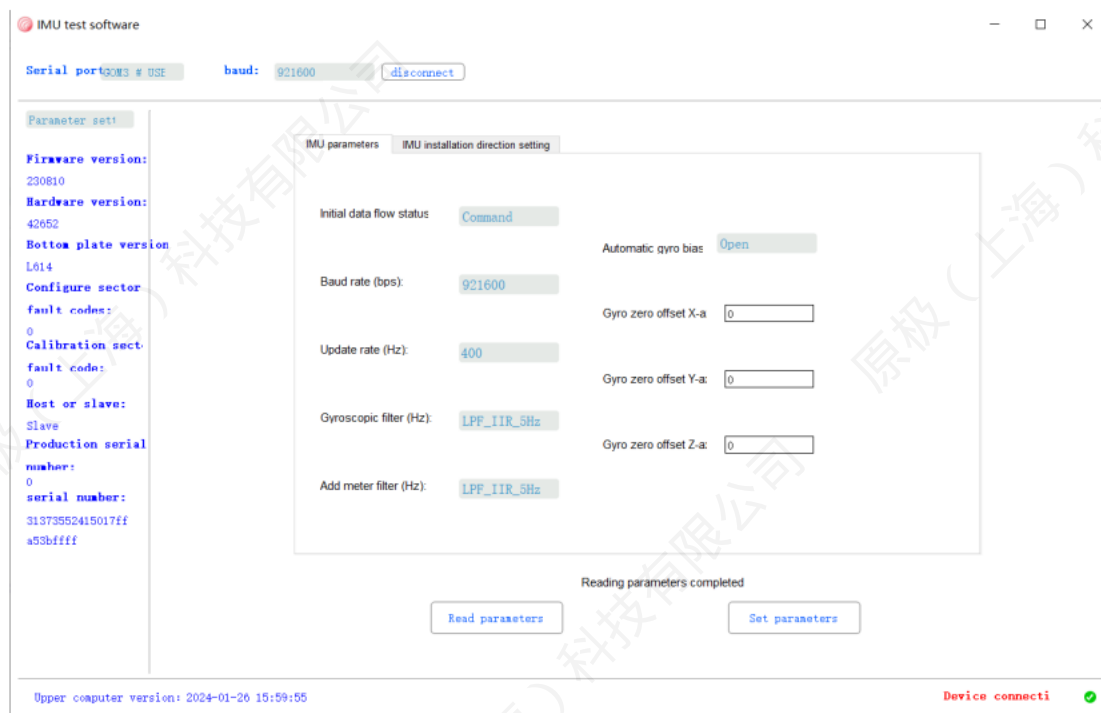
Fig. 5 Forsense PC Software Upgrade Interface



6. User Parameter Functions

With the Forsense PC Software, the user can configure update rates and filter values;

Fig. 6 User Parameter Setting Interface



7. Communication Protocols

7.1 SPI Communication Protocols

Examples of how a STM32-based SPI master reads driver:

<https://www.forsense.cn/download/>

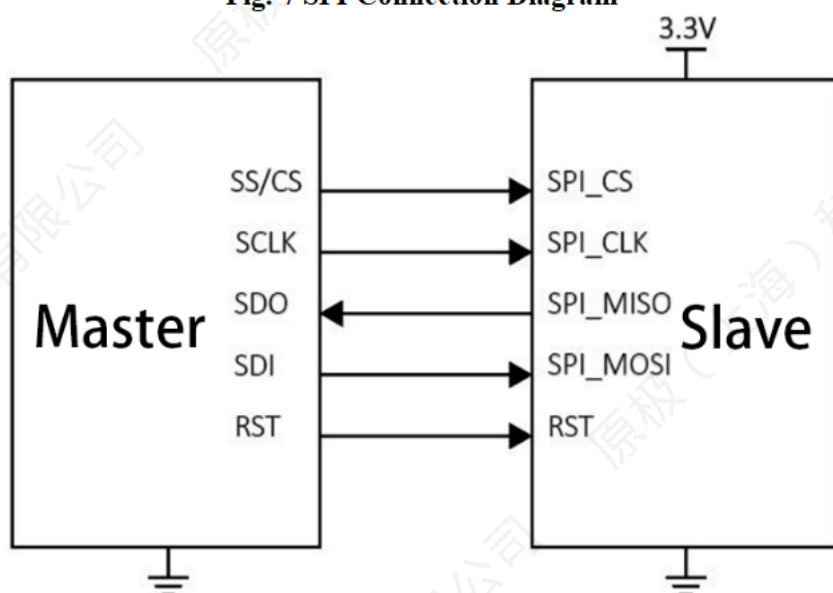
7.1.1 SPI Interface Parameters

Table 7 SPI Interface Parameters

SPI master	This product acts as a slave
SPI rate	0.2~2MHz
SPI word length	16bit
Phase	Rising edge trigger (mode 3, CPHA=1)
Polarity	Idle high state (mode 3, CPOL=1)
Bit sequence	MSB-First

7.1.2 SPI Connection Diagram

Fig. 7 SPI Connection Diagram



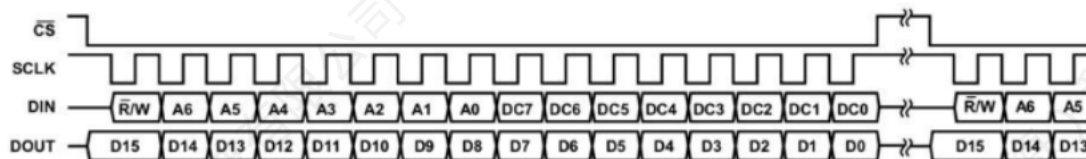
Note 1: Before the master initialization and data reading, reset the IMU and wait for 3s to make it enter normal operating mode.

Note 2: Refer to the corresponding manuals for the SPI pins of different IMU models.

7.1.3 SPI Communication Bit Sequence

The SPI interface supports full-duplex serial communication (simultaneous transmitting and receiving) using the bit sequence shown below.

Fig. 8 SPI Communication Bit Sequence Diagram



The highest bit of DIN indicates read/write operation, [A6:A0] indicates the register address, and [DC7:DC0] indicates the written data (write operation) or DUMMY data (read operation).

When /W =1, the DOUT data of this SPI cycle is meaningless. When /W =0, the DOUT data of this SPI cycle represent the register output data of the last two cycles, seeing the BURST reading example for details.

7.1.4 SPI Register

Table 8 SPI Register List

Name	Address	Read/Write	Default Value	Window ID	Description
BURST	0x00	RW		0	Continuous reading
FILTER_CTRL	0x07,0x06	RW	0x00BB	1	Filter selection
PROD_ID1	0x6C	R	0x494d	1	ID No. 1
PROD_ID2	0x6E	R	0x5536	1	ID No. 2
PROD_ID3	0x70	R	0x3132	1	ID No. 3 (IMU612)
			0x3134	1	ID No. 3 (IMU614)
			0x3138	1	ID No. 3 (IMU618)
			0x3141	1	ID No. 3 (IMU6132A)
			0x3142	1	ID No. 3 (IMU16488)
WIN_CTRL	0x7F,0x7E	RW	0x0000	0, 1	Window ID selection
TEMP	0x0E	R	\	0	Temperature low byte
XGYRO_HIGH	0x12	R	\	0	Gyro X-axis high byte

XGYRO_LOW	0x10	R	\	0	Gyro X-axis low byte
YGYRO_HIGH	0x16	R	\	0	Gyro Y-axis high byte
YGYRO_LOW	0x14	R	\	0	Gyro Y-axis low byte
ZGYRO_HIGH	0x1A	R	\	0	Gyro Z-axis high byte
ZGYRO_LOW	0x18	R	\	0	Gyro Z-axis low byte
XACCEL_HIGH	0x1E	R	\	0	Accel X-axis high byte
XACCEL_LOW	0x1C	R	\	0	Accel X-axis low byte
YACCEL_HIGH	0x22	R	\	0	Accel Y-axis high byte
YACCEL_LOW	0x20	R	\	0	Accel Y-axis low byte
ZACCEL_HIGH	0x26	R	\	0	Accel Z-axis high byte
ZACCEL_LOW	0x24	R	\	0	Accel Z-axis low byte
X_MAGN	0x28	R	\	0	X-axis magnetometer
Y_MAGN	0x2A	R	\	0	Y-axis magnetometer
Z_MAGN	0x2C	R	\	0	Z-axis magnetometer
BAROM_LOW	0x2E	R	\	0	Barometer low byte
BAROM_HIGH	0x30	R	\	0	Barometer high byte

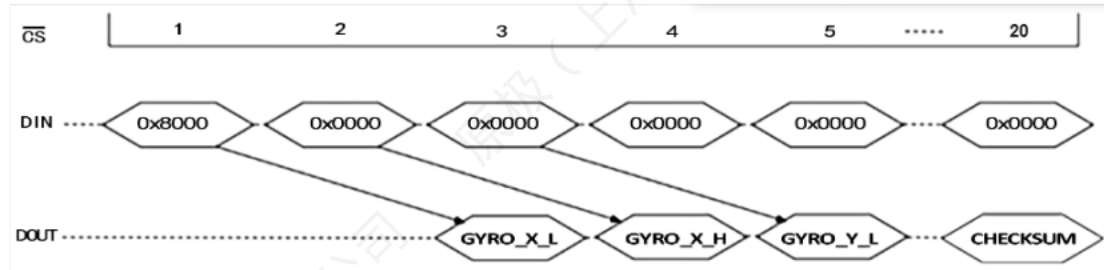
7.1.4.1 SPI BURST Register

BURST is a sequential read register that reads all data in a single stream with no stopping between each 16-bit segment.

Table 9 SPI BURST Register Format

Address	bit15	bit14	bit13	bit12	bit11	bit10	bit9	bit8	Read/Write
0x01									RW
Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Read/Write
0x00	BURST_CMD								RW

The BURST read method is as follows: send 0x8000 to set BURST and start reading, then send 0x0000 all the time to receive the data. The output register content is offset by 2 SPI cycles from the reading instructions sent, and the chip select stays low all the time during the reading period.

Fig. 9 SPI BURST Continuous Reading Diagram

Table 10 SPI BURST Continuous Reading Basic Format

Transmit sequence	1	2	3	4	5	6
Transmit content	GYRO_X_L	GYRO_X_H	GYRO_Y_L	GYRO_Y_H	GYRO_Z_L	GYRO_Z_H
Transmit sequence	7	8	9	10	11	12
Transmit content	ACCL_X_L	ACCL_X_H	ACCL_Y_L	ACCL_Y_H	ACCL_Z_L	ACCL_Z_H
Transmit sequence	13	14	15	16	17	18
Transmit content	X_MAGN	Y_MAGN	Z_MAGN	BAROM_LOW	BAROM_HIGH	CHKSM

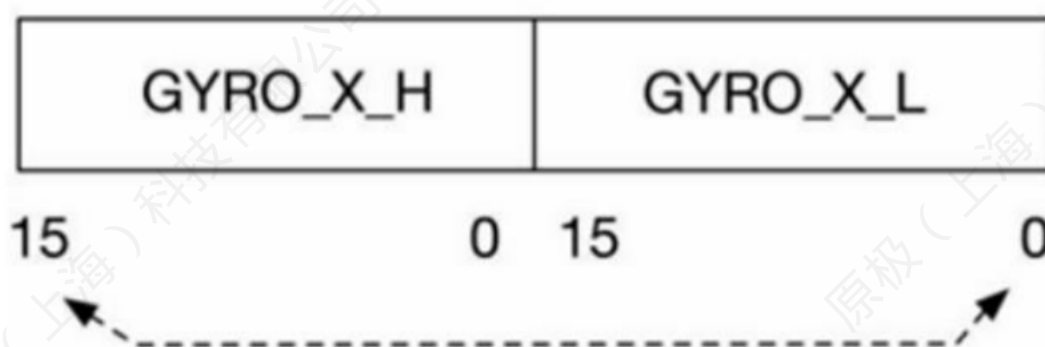
Note 1: All data are in 16-bit width.

Note 2: The data from gyroscopes and accelerometers are spliced together and represented in the int32 format.

Note 3: CHKSM is CHECKSUM, which is used to confirm data integrity. The calculation method is to sum up all the data before CHECKSUM.

In the BURST continuous reading process, the 32-bit complete data is split into high 16-bit and low 16-bit output respectively, and the output adopts the little-endian mode, that is, the low byte is output first. Users need to splice these two parts of 16-bit data to restore the complete 32-bit data.

Fig. 10 SPI 32-bit Data Restoration Diagram



32-bit Gyroscope Data Format

After acquiring the complete 32-bit data, standard frame users get the information of angular velocity, acceleration, temperature and attitude angle by applying the following formulas.

Table 11 Standard Frame SPI 32-bit Data Conversion Formulas

Name	Unit	Formulas	Conditions/Remarks
Angular velocity	°/s	$G = SF * GYRO$	GYRO represents the GYRO data for the X, Y, and Z axes in the table above <ul style="list-style-type: none"> Burst mode, $SF = 0.2$ Single register mode, $SF = 0.016 * 65536$
Acceleration	mg	$A = SF * ACCL$	ACCL represents the ACCL data for the X, Y, and Z axes in the table above. <ul style="list-style-type: none"> Burst mode, $SF = 0.2$ Single register mode, $SF = 0.2 * 65536$
Temperature	°C	$T = SF * (TEMP - 2634) + 25$	TEMP represents the TEMP data in the table above. <ul style="list-style-type: none"> Temperature scale factor $SF = -1/263.4$

Attitude angle	°	$D = SF/65536 * ATT$	ATT represents the ATT data in the table above <ul style="list-style-type: none"> Attitude scale factor SF = 0.00699411
Magnetometer	mgauss	$MA = SF * MAGN$	MAGN represents the MAGN data for the X, Y, and Z axes in the table above. <ul style="list-style-type: none"> Burst mode, SF = 0.1 Single register mode, SF = 0.1*65536
Barometer	μba	$BR = SF * BAROM$	BAROM represents the BAROM data for the X, Y, and Z axes in the table above. <ul style="list-style-type: none"> Burst mode, SF = 64 Single register mode, SF = 64*65536

7.1.4.2 SPI FILTER_CTRL Register

The **FILTER_CTRL** register provides users with the control of digital low-pass filters. This register is readable/writable. The write command is to send 0x86XX and the current SPI cycle setup is valid; the read command is to send 0x0600 and the output register content is offset by 2 SPI cycles from the read command sent.

Table 12 SPI FILTER_CTRL Register Format

Adresse	bit15	bit14	bit13	bit12	bit11	bit10	bit9	bit8	Read/Write
0x07									RW
Adresse	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Read/Write
0x06	Accelerometer filter configuration				Gyroscope filter configuration				RW

Table 13 Filter configuration

	Encoding	Description
Accelerometer/gyroscope filter configuration	4'b 0000	IIR filter fc=1 Hz
	4'b 0001	IIR filter fc=1 Hz

	4'b 0010	IIR filter fc=2 Hz
	4'b 0011	IIR filter fc=5 Hz
	4'b 0100	IIR filter fc=10 Hz
	4'b 0101	IIR filter fc=15 Hz
	4'b 0110	IIR filter fc=20 Hz
	4'b 0111	IIR filter fc=25 Hz
	4'b 1000	IIR filter fc=30 Hz
	4'b 1001	IIR filter fc=35 Hz
	4'b 1010	IIR filter fc=40 Hz
	4'b 1011	No filter

Note: For example, if you configure the gyroscope and accelerometer filters to be 10Hz, write the value 0x8644.

7.1.4.3 SPI ID Register

ID register is a read-only register, the data content is the character "IMU" encoded in ASCII, and the read method is similar to BURST data reading: send 0x6A00~0x7000 and receive data. The output register content is offset by 2 cycles from the read command sent.

Splicing 4 16-bit ID data into ASCII code to obtain the complete ID of the product. The splicing method is the same as that of BURST continuous read data, with PROD_ID1 in the high bit and PROD_ID4 in the low bit.

Table 14 SPI ID Register Format

Address	bit15 ~ bit0	Encoding	Read/Write
0x6C	PROD_ID1	0x494D	R
0x6E	PROD_ID2	0x5536	R
0x70	PROD_ID3 The code content represents the product ID.	0x3132(IMU612)	R
		0x3134(IMU614)	R
		0x3138(IMU618)	R
		0x3141(IMU6132A)	R
		0x3142(IMU16488)	R

7.1.4.4 SPI WIN_CTRL Register

This register is used to control and switch window ID and it is readable and writable.

The window defaults to 0. Switch window ID to 1 if writing 0xFE01.

Table 15 SPI WIN_CTRL Register Format

Address	bit15	bit14	bit13	bit12	bit11	bit10	bit9	bit8	Read/Write
0x7F									RW
Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Read/Write
0x7E	WINDOW_ID								RW

Table 16 SPI Register WIN_CTRL.WINDOW_ID Encoding

Name	Encoding	Description
WINDOW_ID	0x00	Window0, start reading data
	0x01	Window1, enter configuration mode

7.2 Serial Communication Protocols

Examples of serial protocols based on QT, ROS and STM32:

<https://www.forsense.cn/download/>

Serial communication has two modes, Stream Mode and Command Mode. IMU enters a specific mode based on corresponding parameters after the IMU has been powered on and initialized.

Stream Mode: Outputting AHRS data at a fixed frequency.

Command Mode: In this mode, the periodic output is stopped and users communicate with the IMU by sending commands, including the GET command which is used to obtain sensor data, status, parameters and other information and to configure the parameters of the IMU.

7.2.1 Serial Port Parameters

Table 17 Serial Port Parameters

Transmission Rate Range	115200bps ~ 1.5Mbps
Default Transmission Rate	115200bps
Start Bit	1 bit
Data Bit	8 bits
Stop Bit	1 bit
Parity Check	/

7.2.2 Packet Format

The IMU output and user input packets consist of the following:

Table 18 IMU Output and User Input Data Structure

Offset	Data type	Name	Description
0	uint8	Frame header 1	IMU output frame header: 0xAA, 0x55
1	uint8	Frame header 2	User input frame header: 0x55, 0xAA

2	uint16	ID Low Byte	Low byte of serial communication frame ID
3		ID High Byte	High byte of serial communication frame ID
4	uint16	Low Byte of Data Length	The low byte of serial communication frame length, and the length represents the number of bytes occupied by the payload, i.e. n
5		High Byte of Data Length	The high byte of serial communication frame length, and the length represents the number of bytes occupied by the payload, i.e. n
6	uint8	Payload (n bytes)	Data Load
6+n	uint32	CRC_CEHCK (32-bit data low bytes)	CRC verification
7+n		CRC_CEHCK (32-bit data low middle bytes)	
8+n		CRC_CEHCK (32-bit data high middle bytes)	
9+n		CRC_CEHCK (32-bit data high bytes)	

Note 1: The data is transmitted in little-endian format, low byte first and high byte second.

Note 2: The initial value of crc32 is 1 and the CRC calculation does not include all the data of the frame itself. Please refer to CRC Look-up Table Calculations at the end of the document.

7.2.3 Stream Frame - AHRS Data

Table 19 Serial AHRS Data Format

	Frame header	Frame header	ID	length	payload	Frame trailer
Data type	uint8	uint8	uint16	uint16	A1	uint32
Encoding	0xAA	0x55	0x0002	0x002C		crc32

Note 1: Maximum output update rate is not greater than 200Hz@115200bps.

Table 20 Serial A1 Load Data Format

Offset	Name	Data type	Unit	Description
0	timer	uint32	μs	Time scale
4	pitch	float	°	Pitch angle
8	roll	float	°	Roll angle
12	yaw	float	°	Yaw angle
16	ax	float	g	X-axis acceleration
20	ay	float	g	Y-axis acceleration
24	az	float	g	Z-axis acceleration
28	gx	float	°/s	X-axis angular velocity
32	gy	float	°/s	Y-axis angular velocity
36	gz	float	°/s	Z-axis angular velocity
40	temp	float	°C	IMU Chip Temperature

Example of acquiring AHRS data stream:

**AA 55 02 00 2C 00 6D 89 16 05 8F C2 65 40 14 AE 07 BF 5C 0F B2 43 25 06 81 3D BC 74
13 3C 60 E5 80 BF EC 51 38 BD 0A D7 A3 BB CD CC CC BC D7 A3 EE 41 0C BF 84 80**

The analysis is as follows:

Table 21 AHRS data stream acquired by Serial A1

Description	Raw value	Parsed value	Description	Raw value	Parsed value
ID	0200	02	Y-axis acceleration	BC74133C	0.009g
Length	2C00	44	Z-axis acceleration	60E580BF	-1.007g
Time scale	6D891605	85363053	X-axis angular velocity	EC5138BD	-0.045°/s
Pitch angle	8FC26540	3.59°	Y-axis angular	0AD7A3BB	-0.005°/s

			velocity		
Roll angle	14AE07BF	-0.53°	Z-axis angular velocity	CDCCCCBC	-0.025°/s
Yaw angle	5C0FB243	356.12°	IMU Chip Temperature	D7A3EE41	29.83°C
X-axis acceleration	2506813D	0.063g	CRC32 verification	0CBF8480	2156183308

7.2.4 Command Mode GET Output - System Status

Table 22 Serial System Status Data Format

	Frame header	Frame header	ID	length	payload	Frame trailer
Data type	uint8	uint8	uint16	uint16	S1	uint32
Encoding	0xAA	0x55	0x00FF	0x002A		crc32

Note 1: The frame length may vary across different IMU models, all representing the length of S1, which requires confirmation based on specific IMU models.

Table 23 Serial S1 Load Data Format

Offset	Name	Data type	Description
0	Software_ver	uint32	Software version number
4	Hardware_ver	uint32	Hardware version number
8	rev	uint16	Reserved bytes
10	sn0	uint32	First SN number
14	sn1	uint32	Second SN number
18	sn2	uint32	Third SN number
22	Board_version	uint32	Base plate version number
26	Rev[16]	Uint8	All subsequent bytes are reserved

Note 1: IMU models have different subsequent reserved bytes which need to be further

confirmed. IMU614E has 16 bytes.

Example: Acquiring system status

Input data: 55 AA 01 00 18 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 BD DB 31 34

Response data: AA 55 FF 00 2A 00 1F 39 03 00 65 6F 01 00 50 83 30 33 35 55 34 50 15 FF 8F 5F FF FF 50 83 FF 1F 29 00 00 00 00 E0 00 07 10 17 08 50 D0 37 10 3B 7A C3 00 02

The response data are analyzed to get the software version number 211231(1F 39 03 00) and hardware version number 94053(65 6F 01 00).

7.2.5 Command Mode GET Output - Reading Parameters

Table 24 Serial Port Parameter Input Data Format

	Frame header	Frame header	ID	length	payload	Frame trailer
Data type	uint8	uint8	uint16	uint16	P1	uint32
Encoding	0x55	0xAA	0x0006	0x0018		crc32

Table 25 Serial Port Parameter Output Data Format

	Frame header	Frame header	ID	length	payload	Frame trailer
Data type	uint8	uint8	uint16	uint16	P1	uint32
Encoding	0xAA	0x55	0x7530	0x0018		crc32

Note 1: The IMU will turn the data stream off when reading the parameters, and you need to turn the data stream back on after the setup is completed.

Table 26 Serial P1 Load Data Format

Offset	Name	Data type	Description
0	Param1	float	Parameters acquired (input data can be ignored)
4	Param2	float	Reserved, 0 (Default)
8	Param3	uint32	Setting parameter index

12	Param4	uint32	Reserved, 0 (Default)
16	Param5	Int32	Reserved, 0 (Default)
20	Param6	Int32	Reserved, 0 (Default)

Param3	Param1	Unit
3	Support the following serial output baud rates 115200、230400、460800、921600、1500000	bps
4	Coordinate system orientation (see table 34 for coordinate system orientation correspondence)	
8	X-axis gyro bias calibration result, GYRO_X_OFF	°/s
9	Y-axis gyro bias calibration result, GYRO_Y_OFF	°/s
10	Z-axis gyro bias calibration result, GYRO_Z_OFF	°/s
21	AHRS output data rate, 100Hz (Default)	Hz
31	Internal filter configuration as defined in SPI's FILTER_CTRL comparison table	

Table 27 Serial P1 Load Parameter Index

Example: Acquiring AHRS output data rate

Input data: 55 AA 06 00 18 00 00 00 00 00 00 00 00 00 15 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 66 CB 46 AC

Response data: AA 55 30 75 18 00 00 00 48 42 00 00 00 00 15 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 31 2F A2 0A

The response data are analyzed to get the output data rate 50Hz (00 00 48 42).

7.2.6 Command Mode SET Instructions

Table 28 Serial Input Command Format

	Frame header	Frame header	ID	length	payload	Frame trailer
Data type	uint8	uint8	uint16	uint16	R1	uint32
Encoding	0x55	0xAA	CMD	0x0018		crc32

Note 1: CMD and R1 relationship, seeing R1 Load Parameter Index Table for details.

Table 29 Serial R1 Load Data Format

Offset	Name	Data type	Description
0	Param1	float	Setting parameters
4	Param2	float	Reserved, 0 (Default)
8	Param3	uint32	Setting parameter index
12	Param4	uint32	Reserved, 0 (Default)
16	Param5	Int32	Reserved, 0 (Default)
20	Param6	Int32	Reserved, 0 (Default)

Table 30 Serial R1 Load Parameter Index

CMD	Param1	Param3	Description
1	0	0	Triggered to acquire system status data once
2	0	0	Triggered to acquire AHRS data once
3	<mode>	0	Set output modes: Mode=1, outputting AHRS data in a streaming format. Mode=100, disabling Stream Mode and entering COMMAND Mode.
5	0	0	Save current parameters to FLASH
6	0	<value>	Read parameters, and <value> is the parameter index to be read, i.e. P1.index. For details, please refer to Serial Port Parameters Output in Response to Indexes. Examples: set <value>=21 to read

			AHRS output frequency (ODR), set <value>=3 to read the serial port baud rate, set <value>=31 to read the internal filter, and set <value>=4 to read the direction of the coordinate system.
9	0	0	Software restart
14	<value>	3	<p>Set serial output baud rates, and the valid values of the unit BPS are: 115200, 230400, 460800, 921600, 1500000</p> <p>If <value> is the values other than those mentioned above, the default is 115200bps.</p> <p>Restart the software after setting the baud rate parameters.</p> <p>Setup process without power failure: set baud rate, save parameters to FLASH, and restart software.</p>
14	<value>	21	<p>Set the AHRS output data rate (unit: Hz), and the commonly used values for Param1 are 1, 10, 50, 100, 200.</p> <p>Recommended correlation between output data rates and</p>

			serial port baud rates 200Hz: 921600bps 200Hz: 460800bps 100Hz: 115200bps
14	<value>	31	Internal filter configuration, the definition of which is the same as that of SPI accelerometer and gyroscope filter configuration. The default is 0xBB, i.e. 47Hz.
14	<value>	4	Set the IMU coordinate system orientation, the value range is 101~124, and see table 34 for the coordinate system orientation correspondence.

Note 1: Please note that the values in this table are all decimal.

Note 2: You can use the Forsense PC software to generate and send corresponding commands, and the methods of use is shown in the PC software section of this manual.

If the AHRS output is turned on:

CMD ID is filled with 3, parameter 1 is filled with 1, and the generated hexadecimal array can be added to the serial assistant or program array which will be sent to IMU.

Command Generator

[illegible]

CMD ID:

Parameters:

1	<input type="text" value="1"/>	2	<input type="text" value="0"/>	3	<input type="text" value="0"/>
4	<input type="text" value="0"/>	5	<input type="text" value="0"/>	6	<input type="text" value="0"/>

Generate

Send

Set the AHRS output data rate 100Hz

Input data: 55 AA 0E 00 18 00 00 00 C8 42 00 00 00 00 15 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 0A 2B 2C 8D

Response data: AA 55 3D 75 04 00 34 75 15 00 70 2D B2 48

Save current parameters to FLASH

Input data: 55 AA 05 00 18 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 C9 2F E6 32

Response data: AA 55 3D 75 04 00 05 00 01 00 5A CF B1 7C

Set the output mode to AHRS data stream

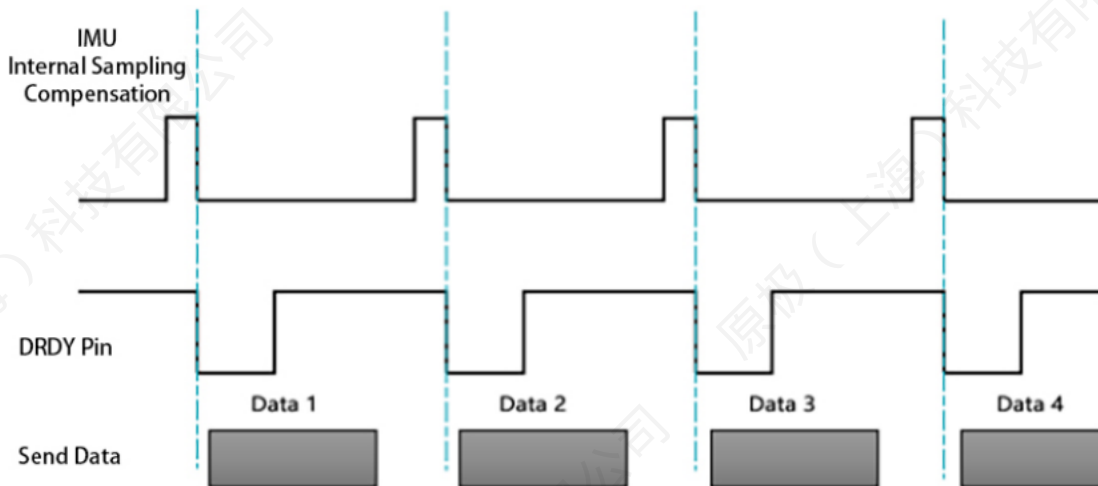
Input data: 55 AA 03 00 18 00 00 00 80 3F 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 52 D8 8E E8

Response data: AA 55 64 00 04 00 03 00 01 00 E7 87 E3 AD

7.2.8 DRDY

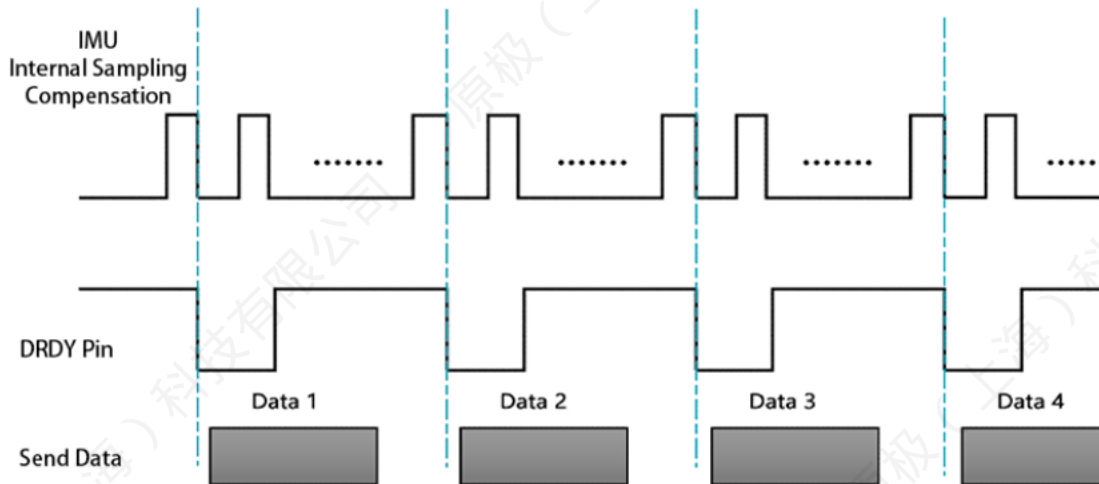
The DRDY pin output serves two purposes:

1. to provide a clock synchronization signal from within the IMU;
2. to provide a signal to indicate the start of data frame transmission.



When the IMU internal sampling frequency (maximum ODR) equals the serial output data rate (current ODR), the DRDY pin will always be pulled down immediately after

the IMU data sampling compensation is completed. At that time, the data frame will be sent from the serial port, and the DRDY pin will be pulled up again in the next cycle.

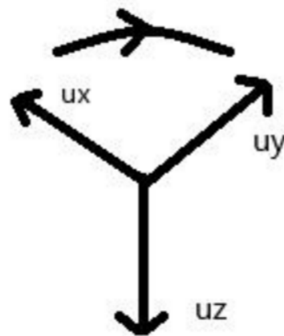


When the serial output data rate is less than the IMU internal sampling frequency, the fractional frequency value (maximum ODR/current ODR) will determine whether the DRDY pin will be pulled down immediately after the IMU data sampling compensation is completed. After DRDY pin is pulled down, the data frame will be sent from the serial port, and the DRDY pin will be pulled up again in the next cycle.

7.2.9 Coordinate System Setup

Set the firmware coordinate system and display the corresponding coordinate system in the Forsense PC software.

Fig. 11 Original Firmware Coordinate System



According to the rules in the above figure, the Z axis is also determined after the X and Y axes are determined. The Z-axis is perpendicular to XY-plane.

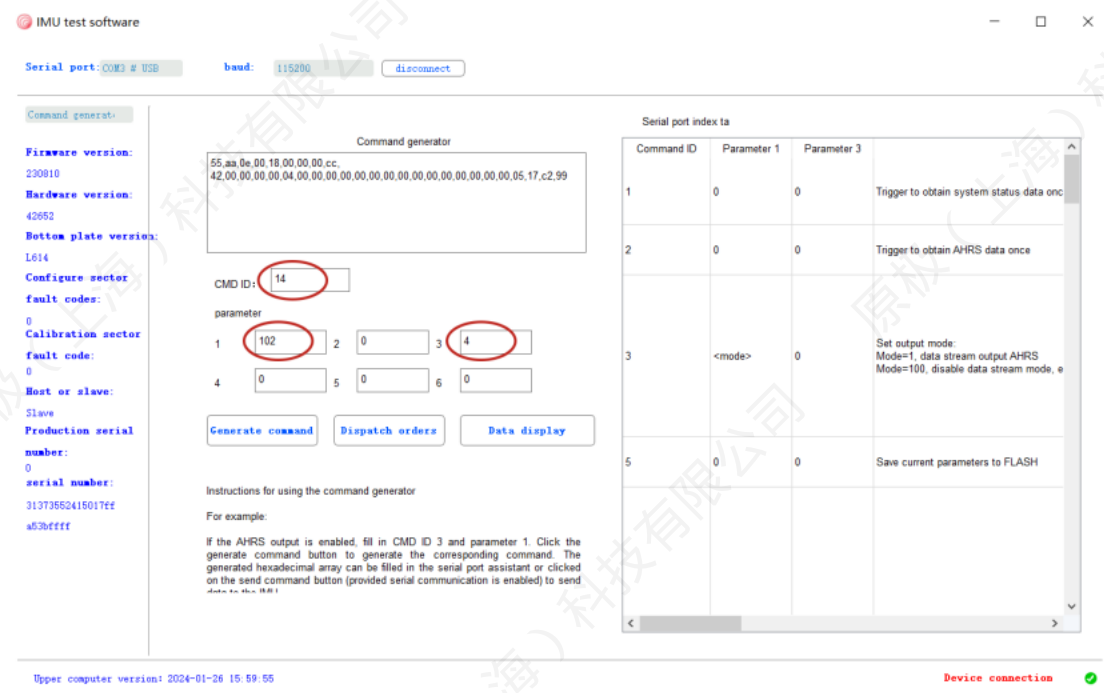
In total, there are 24 orientations for X, Y and Z axes as shown in the table below:

Table 34 Coordinate System Orientation Correspondence

Orientation (value)	XAxis	YAxis	ZAxis	Description
101	+Ux	+Uy	+Uz	Default orientation
102	-Ux	-Uy	+Uz	
103	-Uy	+Ux	+Uz	
104	+Uy	-Ux	+Uz	
105	-Ux	+Uy	-Uz	
106	+Ux	-Uy	-Uz	
107	+Uy	+Ux	-Uz	
108	-Uy	-Ux	-Uz	
109	-Uz	+Uy	+Ux	
110	+Uz	-Uy	+Ux	
111	+Uy	+Uz	+Ux	
112	-Uy	-Uz	+Ux	
113	+Uz	+Uy	-Ux	
114	-Uz	-Uy	-Ux	
115	-Uy	+Uz	-Ux	
116	+Uy	-Uz	-Ux	
117	-Ux	+Uz	+Uy	
118	+Ux	-Uz	+Uy	
119	+Uz	+Ux	+Uy	
120	-Uz	-Ux	+Uy	
121	+Ux	+Uz	-Uy	
122	-Ux	-Uz	-Uy	
123	-Uz	+Ux	-Uy	
124	+Uz	-Ux	-Uy	

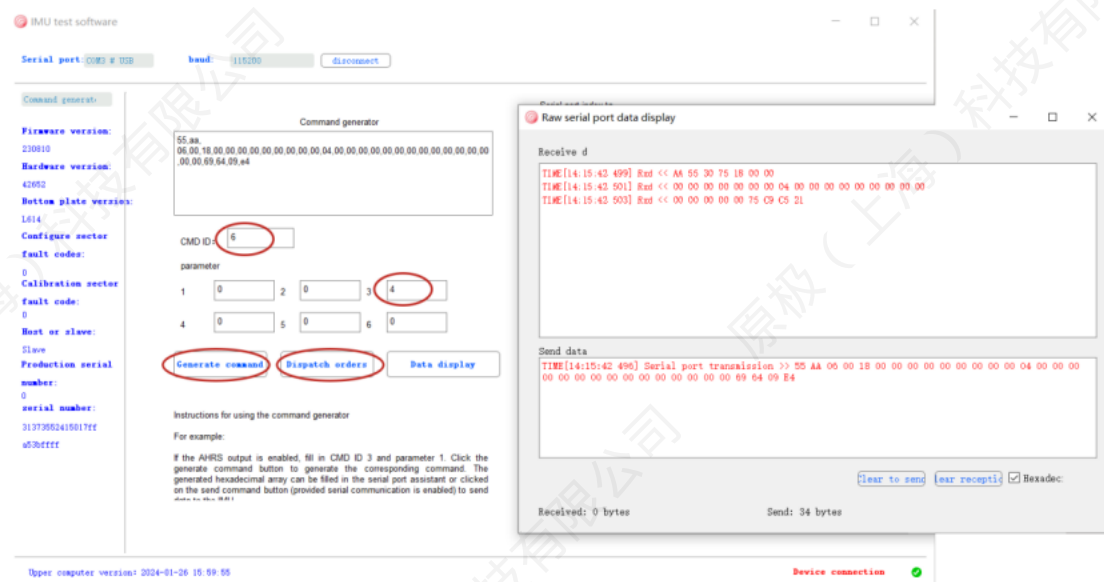
How to change the coordinate system to the orientation 102 :

CMD ID is filled with 14, parameter 1 is filled with 102, and parameter 3 is filled with 4. The generated hexadecimal array can be added to the serial assistant or program array which will be sent to IMU.



How to read the coordinate system orientation:

CMD ID is filled with 06, parameter 3 is filled with 4, and the generated hexadecimal array can be added to the serial assistant or program array which will be sent to IMU.



Example: Set the coordinate system to the orientation 115.

Input data: 55,aa,0e,00,18,00,00,00,e6,42,00,00,00,00,04,00,00,00,00,00,00,00,00,00,00,00,00,00,00,00,00,46,6a,4e,86

Response data: AA 55 3D 75 04 00 34 75 04 00 60 0E 6B 1B

Refer to table 31 to get the parameter index 04, then successfully set.

Read the coordinate system:

Input data: 55 AA 06 00 18 00 00 00 00 00 00 00 00 00 04 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 69 64 09 E4

Response data: AA 55 30 75 18 00 00 00 E6 42 00 00 00 00 04 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 B2 2F 2D 4E

According to tables 25 and 26, parameter 1 is 115 (float) and parameter 3 is 04, which means the orientation of coordinate system is 115.

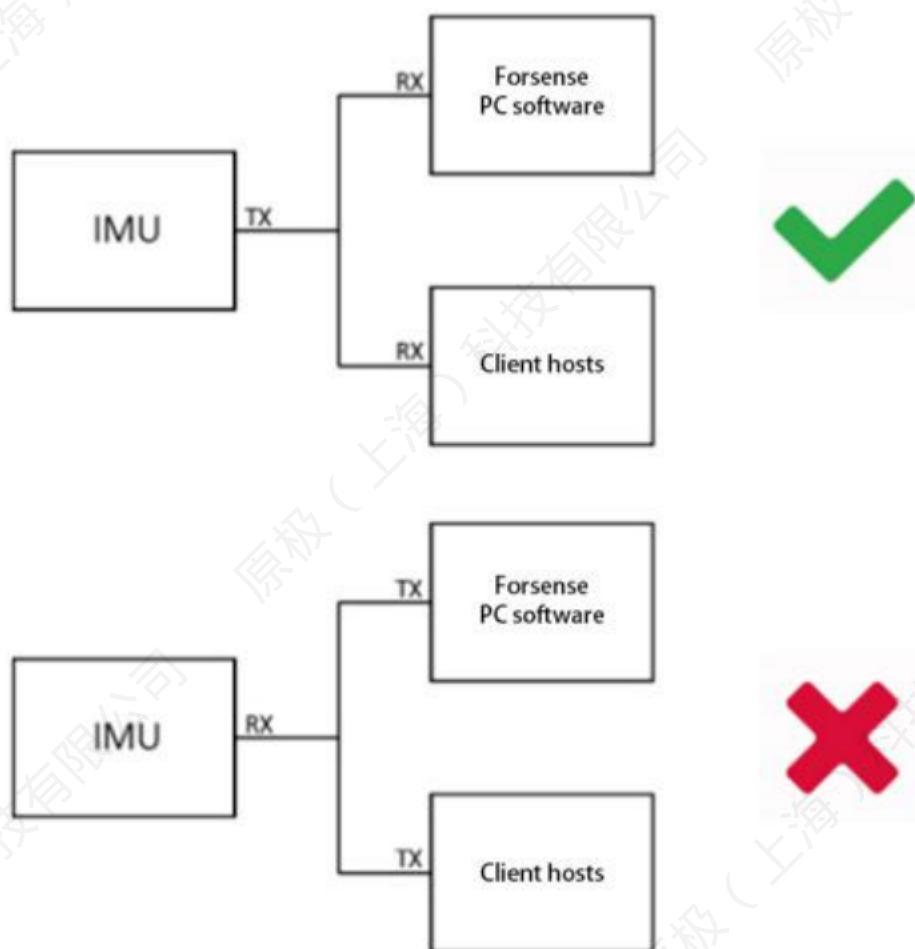
7.2.10 Serial Connection FAQs

1) IMU receiver (RX) can not be connected to 2 master transmitters (TX)

The RX of the serial port can not be connected to the TX of two masters at the same time. If you need to connect to the Forsense PC software, you shall disconnect its serial communication with the user master, otherwise the PC software can only receive the data and cannot send commands to the IMU.

As shown in the figure below:

Fig. 12 Serial Connection Methods



Note: IMU TX can be connected to multiple RXs, but RX **can not** be connected to multiple TXs;
 IMU serial port can not be connected to both the client host and Forsense PC software at the same time;
 IMU can reserve another serial port to connect to only Forsense PC software.

2) Unable to get the version number

Check whether the data is lost, and it is recommended to use the serial cable with FT232

chip. CH340 and PL2303 data cables at high baud rate (>115200bps) will lead to data loss.

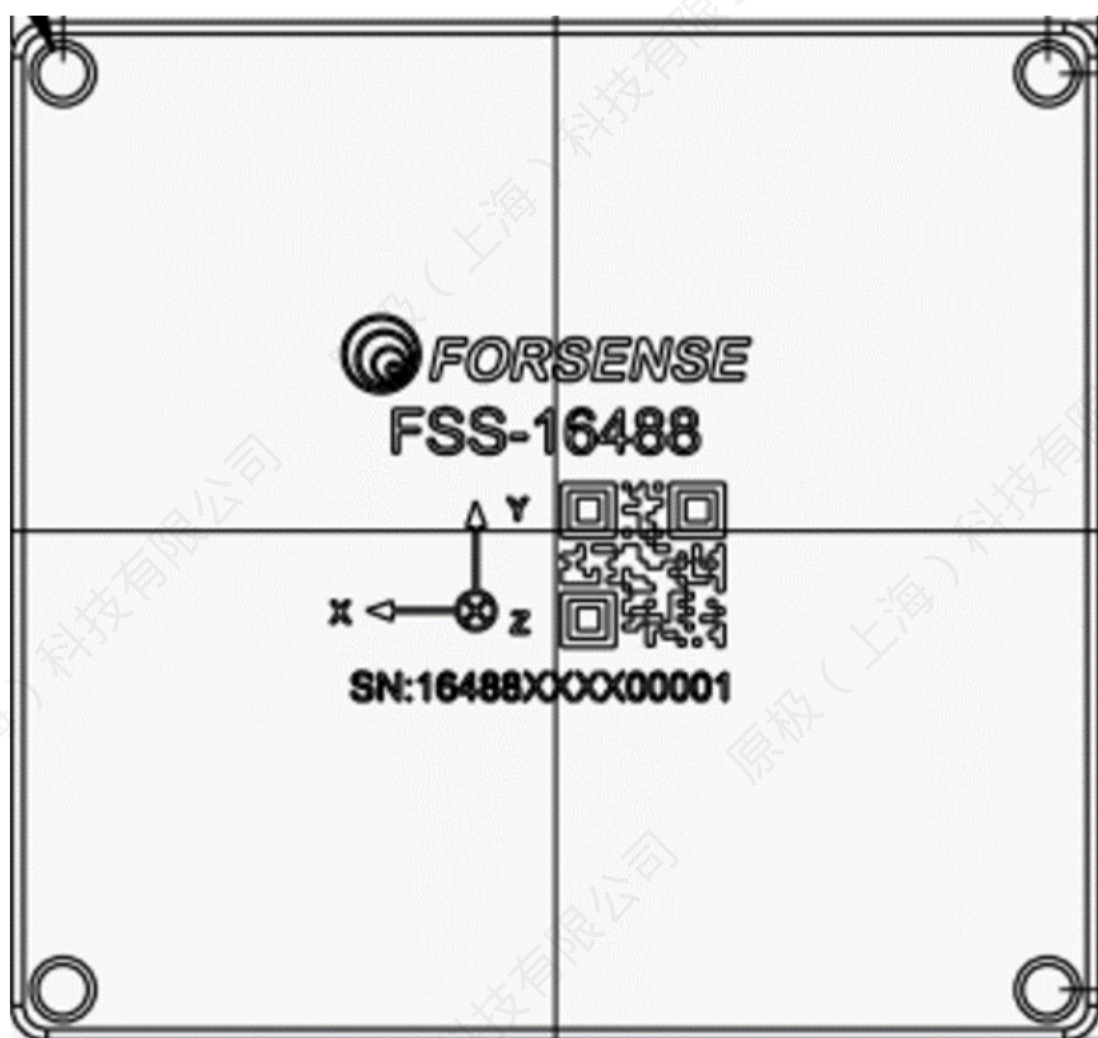
The serial cable should be connected directly rather than in series. For example, when RS422 interface is connected to the computer, it is recommended to directly use the RS422 to USB converter instead of the RS422 to RS232 and the RS232Z to USB converters in series.

3) The PC software curve display is stuck

If using FT232 data cable, open the Forsense PC software by selecting "Run as administrator" and configure the serial delay automatically.

Manually configure serial delay in the device manager.

8. Definition of Coordinate System



This product is equipped with the Front-Right-Down (FRD) coordinate system, and the range of Euler angles is as follows:

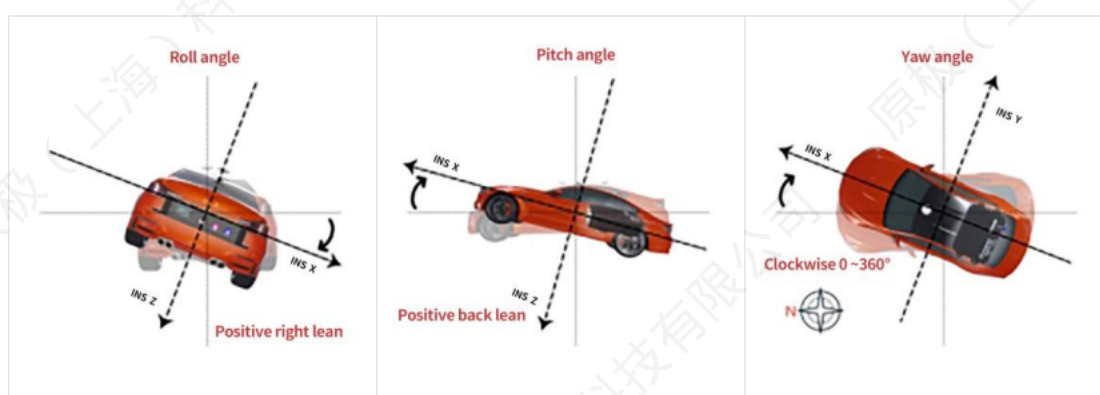
Rotate around Z-axis: Yaw angle range ($0^{\circ} \sim 360^{\circ}$);

Rotate around X-axis: Roll angle range ($-180^{\circ} \sim 180^{\circ}$);

Rotate around Y-axis: Pitch angle range ($-90^{\circ} \sim 90^{\circ}$).

The specific diagram is shown below:

Fig. 21 Diagram of Roll, Pitch, and Pitch Angles



9. CRC Look-up Table Calculations

```
C++
static const uint32_t crc32_tab[] = {
0x00000000, 0x77073096, 0xee0e612c, 0x990951ba, 0x076dc419, 0x706af48f,
0xe963a535, 0x9e6495a3, 0x0edb8832, 0x79dcb8a4, 0xe0d5e91e, 0x97d2d988,
0x09b64c2b, 0x7eb17cbd, 0xe7b82d07, 0x90bf1d91, 0x1db71064, 0x6ab020f2,
0xf3b97148, 0x84be41de, 0x1adad47d, 0x6ddde4eb, 0xf4d4b551, 0x83d385c7,
0x136c9856, 0x646ba8c0, 0xfd62f97a, 0x8a65c9ec, 0x14015c4f, 0x63066cd9,
0xfa0f3d63, 0x8d080df5, 0x3b6e20c8, 0x4c69105e, 0xd56041e4, 0xa2677172,
0x3c03e4d1, 0x4b04d447, 0xd20d85fd, 0xa50ab56b, 0x35b5a8fa, 0x42b2986c,
0xdbbdc9d6, 0xacbcf940, 0x32d86ce3, 0x45df5c75, 0xdcd60dcf, 0xabd13d59,
0x26d930ac, 0x51de003a, 0xc8d75180, 0xbfd06116, 0x21b4f4b5, 0x56b3c423,
0xcfbfa959, 0xb8bda50f, 0x2802b89e, 0x5f058808, 0xc60cd9b2, 0xb10be924,
0x2f6f7c87, 0x58684c11, 0xc1611dab, 0xb6662d3d, 0x76dc4190, 0x01db7106,
0x98d220bc, 0xefd5102a, 0x71b18589, 0x06b6b51f, 0x9fbfe4a5, 0xe8b8d433,
0x7807c9a2, 0x0f00f934, 0x9609a88e, 0xe10e9818, 0x7f6a0dbb, 0x086d3d2d,
0x91646c97, 0xe6635c01, 0x6b6b51f4, 0x1c6c6162, 0x856530d8, 0xf262004e,
0x6c0695ed, 0x1b01a57b, 0x8208f4c1, 0xf50fc457, 0x65b0d9c6, 0x12b7e950,
0x8bbeb8ea, 0xfcb9887c, 0x62dd1ddf, 0x15da2d49, 0x8cd37cf3, 0xfbd44c65,
0x4db26158, 0x3ab551ce, 0xa3bc0074, 0xd4bb30e2, 0x4adfa541, 0x3dd895d7,
0xa4d1c46d, 0xd3d6f4fb, 0x4369e96a, 0x346ed9fc, 0xad678846, 0xda60b8d0,
0x44042d73, 0x33031de5, 0xaa0a4c5f, 0xdd0d7cc9, 0x5005713c, 0x270241aa,
0xbe0b1010, 0xc90c2086, 0x5768b525, 0x206f85b3, 0xb966d409, 0xce61e49f,
0x5edef90e, 0x29d9c998, 0xb0d09822, 0xc7d7a8b4, 0x59b33d17, 0x2eb40d81,
0xb7bd5c3b, 0xc0ba6cad, 0xedb88320, 0x9abfb3b6, 0x03b6e20c, 0x74b1d29a,
0xead54739, 0x9dd277af, 0x04db2615, 0x73dc1683, 0xe3630b12, 0x94643b84,
0x0d6d6a3e, 0x7a6a5aa8, 0xe40ecf0b, 0x9309ff9d, 0x0a00ae27, 0x7d079eb1,
0xf00f9344, 0x8708a3d2, 0x1e01f268, 0x6906c2fe, 0xf762575d, 0x806567cb,
0x196c3671, 0x6e6b06e7, 0xfed41b76, 0x89d32be0, 0x10da7a5a, 0x67dd4acc,
0xf9b9df6f, 0x8ebeeff9, 0x17b7be43, 0x60b08ed5, 0xd6d6a3e8, 0xa1d1937e,
0x38d8c2c4, 0x4fdff252, 0xd1bb67f1, 0xa6bc5767, 0x3fb506dd, 0x48b2364b,
0xd80d2bda, 0xaf0a1b4c, 0x36034af6, 0x41047a60, 0xdf60efc3, 0xa867df55,
0x316e8eef, 0x4669be79, 0xcb61b38c, 0xbc66831a, 0x256fd2a0, 0x5268e236,
0xcc0c7795, 0xbb0b4703, 0x220216b9, 0x5505262f, 0xc5ba3bbe, 0xb2bd0b28,
0x2bb45a92, 0x5cb36a04, 0xc2d7ffa7, 0xb5d0cf31, 0x2cd99e8b, 0x5bdeae1d,
```

```
0x9b64c2b0, 0xec63f226, 0x756aa39c, 0x026d930a, 0x9c0906a9, 0xeb0e363f,  
0x72076785, 0x05005713, 0x95bf4a82, 0xe2b87a14, 0x7bb12bae, 0x0cb61b38,  
0x92d28e9b, 0xe5d5be0d, 0x7cdcefb7, 0x0bdbdf21, 0x86d3d2d4, 0xf1d4e242,  
0x68ddb3f8, 0x1fda836e, 0x81be16cd, 0xf6b9265b, 0x6fb077e1, 0x18b74777,  
0x88085ae6, 0xff0f6a70, 0x66063bca, 0x11010b5c, 0x8f659eff, 0xf862ae69,  
0x616bffd3, 0x166ccf45, 0xa00ae278, 0xd70dd2ee, 0x4e048354, 0x3903b3c2,  
0xa7672661, 0xd06016f7, 0x4969474d, 0x3e6e77db, 0xaed16a4a, 0xd9d65adc,  
0x40df0b66, 0x37d83bf0, 0xa9bcae53, 0xdeb9ec5, 0x47b2cf7f, 0x30b5ffe9,  
0xbdbdf21c, 0xcabac28a, 0x53b39330, 0x24b43a6, 0xbad03605, 0xcdd70693,  
0x54de5729, 0x23d967bf, 0xb3667a2e, 0xc4614ab8, 0x5d681b02, 0x2a6f2b94,  
0xb40bbe37, 0xc30c8ea1, 0x5a05dflb, 0x2d02ef8d,  
}  
uint32_t crc_crc32 (uint32_t crc, const uint8_t *buf, uint32_t size) {  
    for (uint32_t i=0; i<size; i++) {  
        crc = crc32_tab [(crc ^ buf[i]) & 0xff] ^ (crc >> 8);  
    }  
    return crc;  
}
```

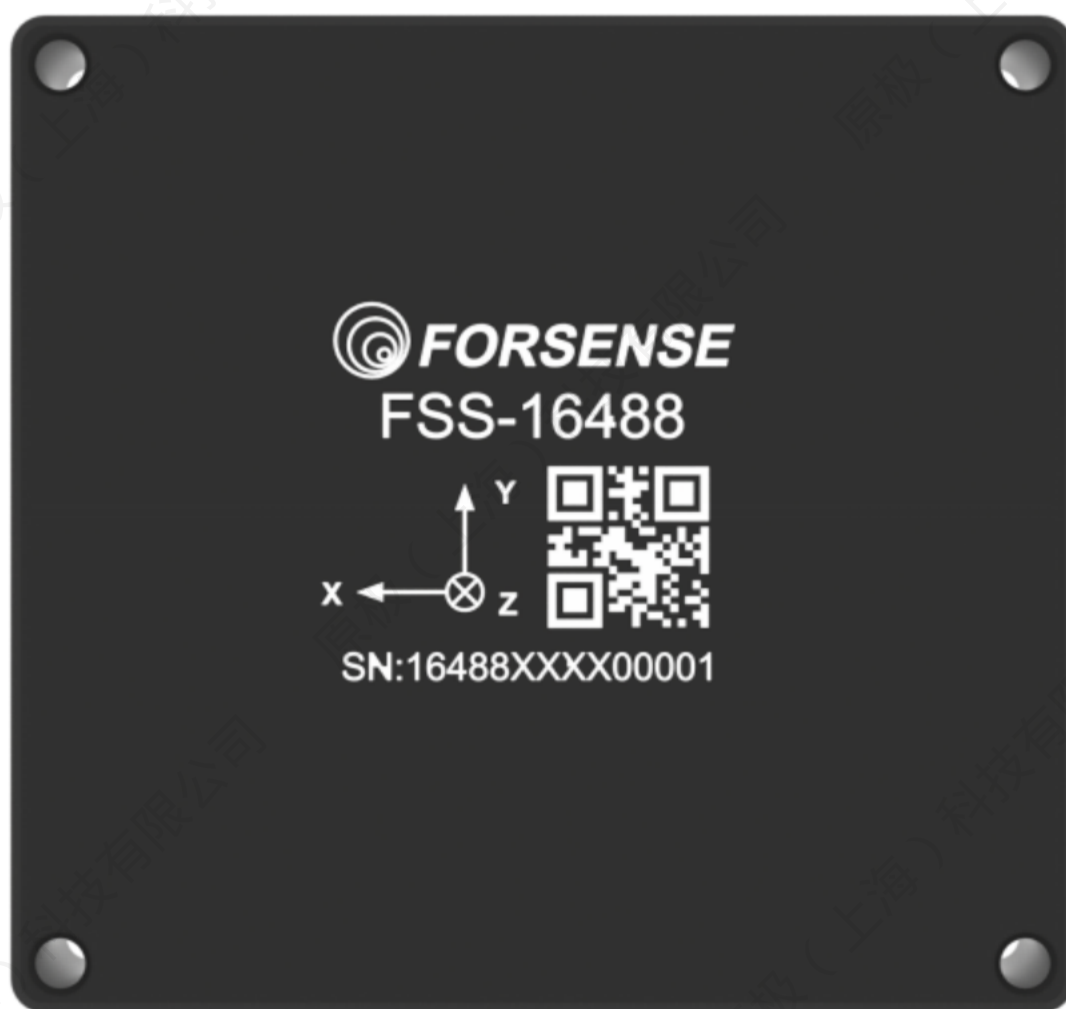
10. Usage Examples

Device Installation

1. The module should be firmly fixed on a rigid plane rather than in a position of high vibration;
2. The module should be installed toward the front of the vehicle.

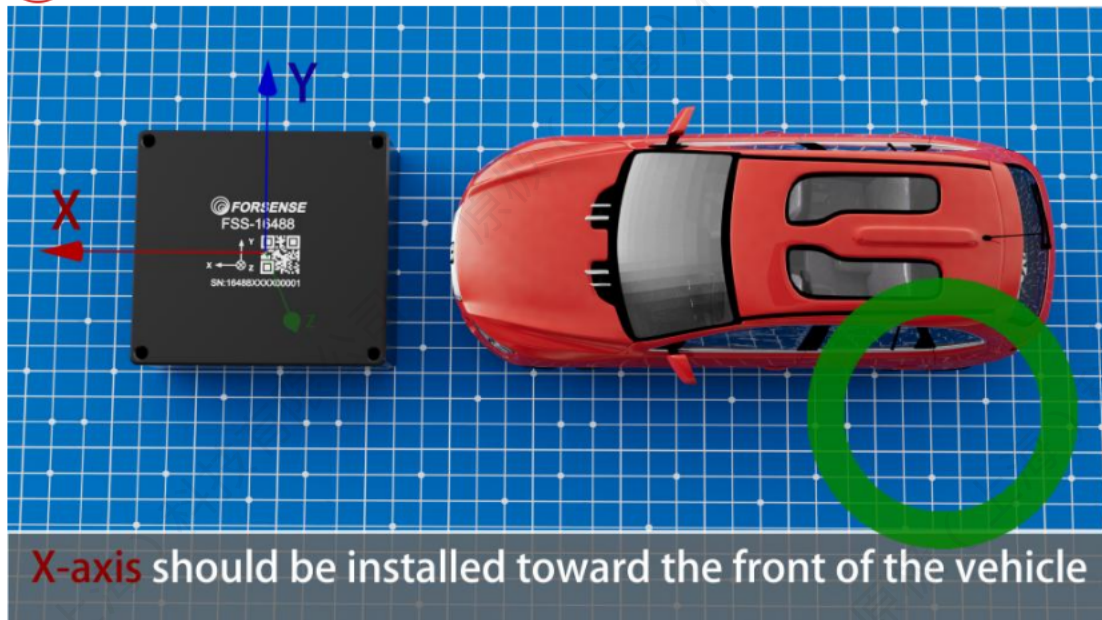
Fig. 11 Module Installation Diagram

The correct installation diagram is as follows

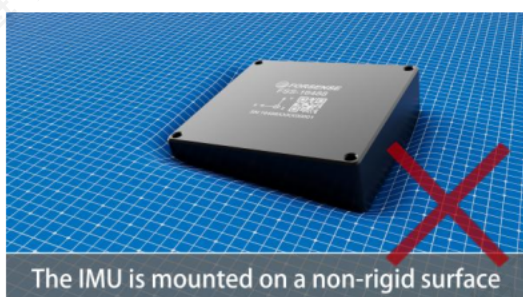
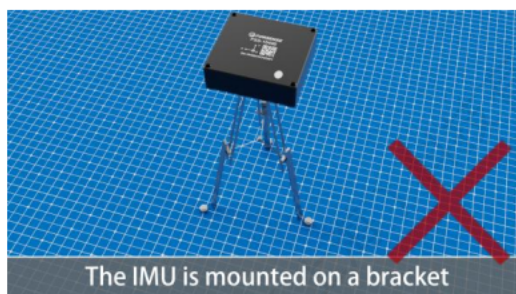
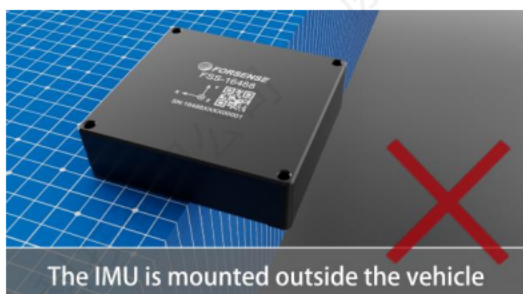
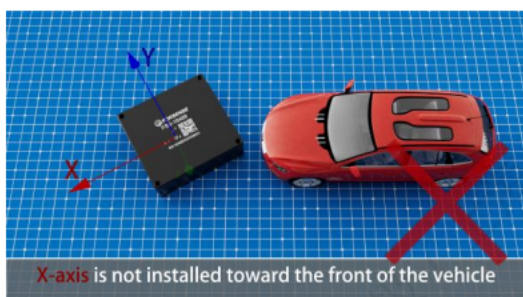


X-axis toward the front of the vehicle

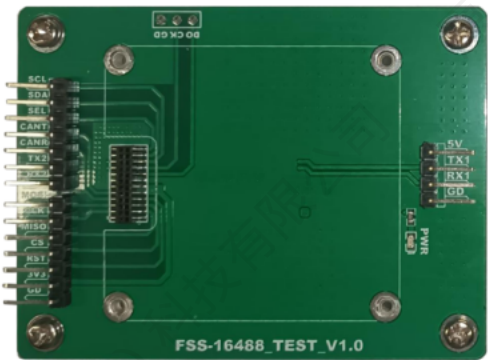

Fig. 12 Correct Installation Diagram



The following mounting methods are incorrect:



11. Optional Accessories

 <p>A green printed circuit board (PCB) labeled 'FSS-16488_TEST_V1.0'. It features a central integrated circuit, various surface components, and a multi-pin connector on the left side. The board is secured with four screws at the corners.</p>	 <p>A black USB-to-TTL serial cable. It has a standard USB-A connector on one end and a 5-pin D-sub connector on the other, with red, green, and white wires visible at the end.</p>
IMU16488 Base Plate	TTL Serial Cable

12. Revision History

Version	Date	Status/Notes
Version 1.0	2023.10.07	First release
Version 1.1	2023.12.14	Added accessories
Version 1.2	2024.02.04	Updated electrical characteristics
Version 1.3	2024.03.22	Updated product description
Version 1.4	2024.04.11	Added use cases
Version 1.5	2024.05.10	Added connection diagrams of the Forsense PC software