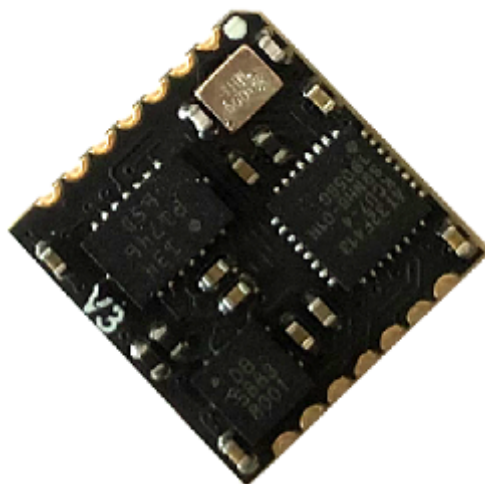


# HI226/HI229 User Guide

IMU/VRU/AHRS attitude measuring module, Rev A1



## HI226/HI229 User Guide

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- AT+GWID

- AT+URFR

- AT+INFO

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- Conversion between quaternions, rotation matrices, and Euler angles

  - Quaternion -> Rotation matrix

  - Quaternion -> Euler angles

  - Euler angles -> Quaternion

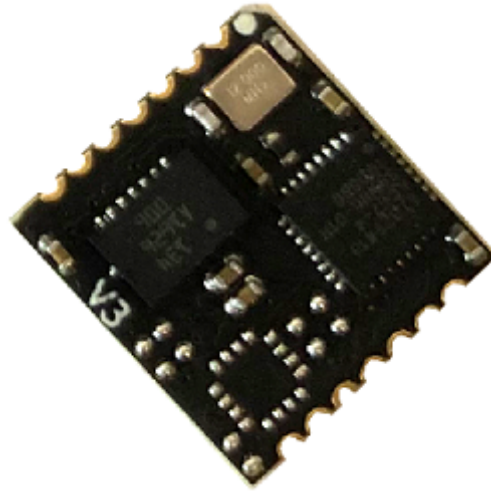
  - Euler angles -> Rotation matrix (n->b)

  - Rotation matrix (n->b) -> Euler angles

#### Appendix C - Firmware Upgrade and Factory Reset

# Introduction

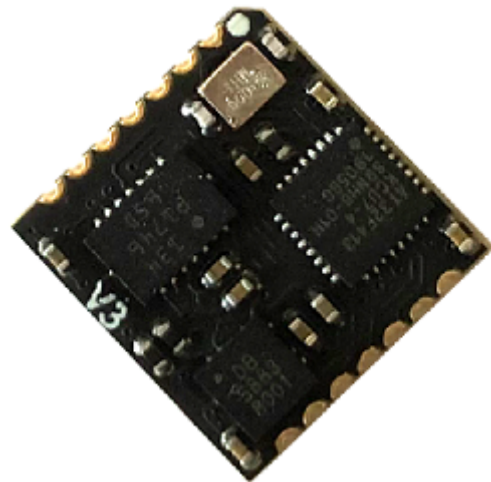
HI226 is a miniature inertial measurement unit (IMU) system launched by HIPNUC. This module features low cost, high performance, small size, and low latency. This module integrates a 3-axis accelerometer, a 3-axis gyroscope and a MCU, and can output accurate 3D attitude data which is calibrated by factory, including relative heading, pitch, and roll angles (without absolute reference). It can also output raw sensor data.



Typical application:

- Sweeping robot / Indoor robot positioning/ Mouse / Game controller

Different from HI226, HI229 also integrates 3-axis magnetometer. HI229 is a low-cost, high-performance, small-size, low-latency Attitude Reference Unit (AHRS), integrating a 3-axis accelerometer, a 3-axis gyroscope, a 3-axis magnetometer, and a micro-controller. HI229 has the same features as HI226, but HI229 can output absolute heading directions and even work under harsh magnetic environments.



Typical application:

- VR \ Motion capture
- Motion performance evaluation \ Attitude measurement in high dynamic environment
- Drone control

## Features

### On-board sensors

- Three-axis gyroscope with
  - maximum range:  $\pm 2000$  °/s
  - output rate up to 2000Hz

- Three-axis accelerometer with
  - maximum range:  $\pm 8g$
  - output rate up to 125Hz
- Three-axis magnetic field sensor with
  - maximum range: 800mG
  - internal sampling rate up to 100Hz

## Data process

- Accelerometer and gyroscope are calibrated by factory to correct 3-axis non-orthogonal and scale factor error.
- Quaternions and Euler angles are calculated in geographic coordinate system by data fusion algorithm.

## Communication interface and power supply of HI226 and HI229

- Serial port (compatible with TTL, which can be directly connected with 5V or 3.3V serial port device)
- Supply voltage: 3.3 (+/- 100 mV)
- Power consumption at peak : 32mA

## Others

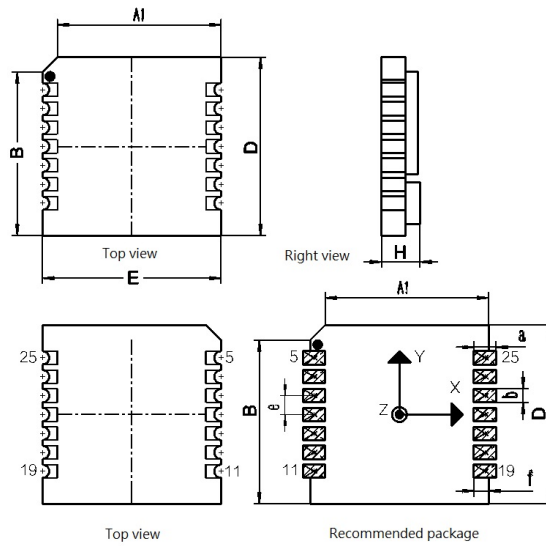
- We provide GUI on the PC(Win)side, providing real-time data display, waveform, calibration and data logging functions.
- Configurable parameters.

## Hardware Specifications

### Specifications

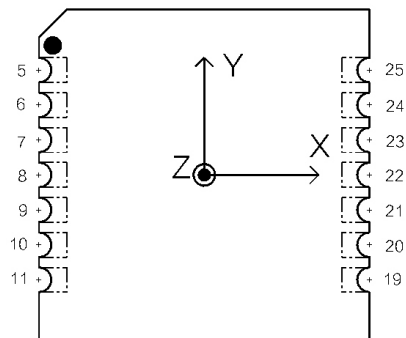
Parameter	Description
Data Interface	UART (TTL 1.8V - 3.3V)
Supply Voltage	3.3V ( $\pm 100mV$ )
Power Consumption	86mW @3.3V
Temperature Tolerance	-20°C - 85 °C
Maximum Linear Accelerations	0 - 115 $m/s^2$
Size	12 x 12 x 2.6mm (W x L x H)
On-board Sensors	3-axis gyroscope, 3-axis accelerometer (HI226 & HI229). Hi229 has 3-axis magnetometer in addition.

## Size



Symbol	Minimum	Type Value	Maximum	Unit
A1	-	11	-	mm
B	-	11	-	mm
D	-	12	-	mm
E	-	12	-	mm
H	2.5	2.6	2.7	mm
a	-	1.5	-	mm
b	-	0.9	-	mm
c	-	1	-	mm
e	-	1.27	-	mm
f	-	1	-	mm

## Pin Definition



Pin Number	Name	Description
5	N/C	Reserved.
6	VCC	Power input 3.3V
7	SYNC_OUT	Data output synchronization: This pin is high when data is outputting, and low when it's idle.
8	RXD	Module UART receive pin. (Connect TXD on host(MCU))
9	TXD	Module UART transmit pin. (Connect RXD on host(MCU))
10	SYNC_IN	Data input synchronization: internal pull down. The module outputs a frame of data when detecting a rising edge. The maximum synchronization frequency is 200Hz, and the output frame rate cannot exceed total bandwidth of the current serial port Baud rate.
11	N/C	Reserved.
19	GND	GND
20	RST	Reset. internal pull up. >10uS Low-level reset module. No external resistors or capacitors are required. It is recommended to connect the GPIO pins on MCU to implement controllable hardware reset.
21	N/C	Reserved.
22	N/C	Reserved.
23	N/C	Reserved.
24	GND	GND
25	N/C	Reserved.

## Performance

### Output accuracy of attitude

Attitude	Type
Roll Angle \ Pitch Angle - Error at static situations	0.8°
Roll Angle \ Pitch Angle - Error at dynamic situations	2.5°
Stability of Zero Offset	10°/h
Heading angle accuracy during movement (in 9-axis mode, without magnetic interference and after geomagnetic calibration)	3°

### Gyroscope

Parameter	Value
Measuring Range	±2000°/s
Non-linearity	±0.1% (Has best performance at 25°)
Noise density	0.08°/s/ $\sqrt{Hz}$
Sampling Rate	2000Hz

### Accelerometer

Parameter	Value
Measuring Range	±8G (1G = 1x Gravitational acceleration )
Non-linearity	±0.5% (Has best performance at 25°)
Maximum Zero Offset	10mG
Noise Density	250 $\mu\text{G}\sqrt{\text{Hz}}$
Sampling Rate	500Hz

## Magnetometer

Parameter	Value
Measuring Range	±8Gauss
Non-linearity	±0.1%
Sampling Rate	100Hz

## Data interface specifications

Parameter	Value
Serial Output Baud Rate	4800/9600/115200/460800 (Optional)
Output frame rate	0/1/10/25/50/100/200/400/500Hz (Optional)

## Data Fusion and Calibration Algorithm

### Calibration of gyroscope

- Each attitude sensor is individually calibrated and tested over the full measurement range. The non-orthogonal and scale factor error of the gyroscope and accelerometer are stored in internal flash.
- To obtain the best performance, the automatic calibration process of the gyroscope needs to be stationary for about 3s after powering on.
- If the time for stillness is less than 3s, the accuracy of the gyro zero offset calibration will be reduced.
- The attitude sensor has a built-in gyro zero speed detection mechanism. When three-axis gyro speed is less than  $1^\circ/\text{s}$  for a period of time, the module considers attitude is stationary and the gyro output regards as zero bias. The gyro sensor output are considered as bias. So **This product cannot be used in scenarios with rotation speed  $<1^\circ/\text{s}$** . (In other words, the rotation speed is lower than 1/6 of the average speed of the second pin of a clock)

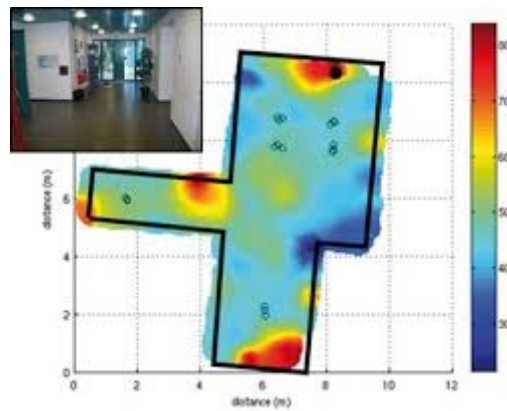
## Magnetic interference, Distortion rejection and magnetic calibration

### Type of magnetic interference

- Interference in space
  - Definition:  
Interference exists in the world coordinate system and does not move with sensor motion.
  - Typical source:  
Various fixed sources of magnetic interference. For example, furniture, household appliances, cables, reinforced structures in houses, etc, are the sources. They don't move with the magnetic sensor.
  - Interference:  
No matter how properly the magnetic field sensor is calibrated, the interference of these spatial magnetic fields (or the unevenness of the environmental magnetic field) will always cause the spatial geomagnetic field to be distorted. They will cause errors in geomagnetic compensation and heading angle. They are the main factors that make troubles to indoor geomagnetic fusion. This kind of interference cannot be calibrated, and it will seriously affect the geomagnetic performance especially the space magnetic interference indoors .

- Measure:  
Module has built-in homogeneous magnetic field detector and shielding of non-homogeneous magnetic field.
- Interference in the sensor coordinate system
  - Definition:  
Interference source moves with sensor motion.
  - Typical source:  
The printed circuit board of our module, and board and any device that attached with the module, are all regarded as the same rigid body as the magnetometer, and move with the magnetometer.
  - Interference:  
Make hard magnetic / soft magnetic interference to the sensor.
  - Measure:  
These interferences can be well eliminated by our geomagnetic calibration algorithm.

The following figure shows a distribution map of typical indoor magnetic field. The spatial magnetic field distortion is servers indoors.



### Notes

The spatial magnetic interference is particularly serious indoors, and it cannot be eliminated by calibration. Although the module has built-in homogeneous detector of magnetic field and shielding mechanism, the accuracy of the 9-axis mode heading angle is susceptible to the distortion of indoor magnetic field. If the indoor magnetic field of environment is messy, such as being near a computer room, electromagnetic experiments rooms, workshops, underground garages, the accuracy of heading angle of 9-axis mode may not be as good as that of the 6-axis mode, and even having large errors of angle after calibration.

### Operation mode

The geomagnetic field is very susceptible to spatial interference, therefore you should be very careful when using the 9-axis mode. The following table lists the suggestions for different usage and working conditions.

- 6-axis mode
  - Suitable environment : Anywhere.
  - Typical usage : Low dynamic attitude detection such as PTZ and indoor robot.
  - Advantage :
    1. Output of attitude angle is stable
    2. The sensor is completely immune to magnetic interference.
  - Disadvantage : Heading angle drifts slowly over time
- 9-axis mode
  - Suitable environment : No magnetic environment
  - Typical usage :
    1. Compass, north seeking system



2. Use in an empty room with less magnetic interference, or less moving device in an area. For example, capture motion in a studio,
- Advantage :
    1. The heading angle does not drift with time.
    2. The heading angle can be quickly corrected to the north once the geomagnetic field is detected.
  - Disadvantage : Any magnetic interference will reduce the accuracy of heading angle. In the case of severe interference indoors, the heading angle can not point to the correct direction. In addition, the metal structure of the mobile robot and the motor will generate strong magnetic interference, which make mobile robot platform not applicable for 9-axis mode.
  - Note : You need to calibrate geomagnetic sensor before using it.

## Geomagnetic Calibration

The module's automatic geomagnetic calibration system can only handle fixed magnetic field interference that is installed with the module, or this interference must be fixed in around, or the distance between interferences and the module should be constant. For example, while the module is installed on an iron material, the iron and the module need to be rotated and calibrated together because there is magnetic field interference from iron. Furthermore, the iron won't be separated from the compass during the using. If they are separated, it needs to be recalibrated. Beware, if the size of the iron is not fixed, or the distance between interferences and the module is not fixed, calibrations won't make effect. Even if it calibrate successfully, the accuracy will still be very poor. The only solution is to keep those interferences away at least 40CM.

This module integrates an active non-interference geomagnetic calibration algorithm. The module will automatically collect the geomagnetic field information and perform hard magnetic calibration, which is also called the geomagnetic sensor zero offset. After the calibration successes, the calibration information will be saved in the flash memory for the future use. Users do not need any operation to realize the geomagnetic calibration. However, In the first time you use the module and set it to 9-axis mode, you should follow those steps:

1. Slowly perform 8-shaped motion or 360 degrees around each axis of the module in a small range, and hold the posture of module as various as possible.
2. If the geomagnetic interference is within a acceptable range, the calibration can be completed. It's unnecessary to recalibrate in the same geomagnetic environment or the same location. If the module couldn't be calibrated successfully, you should suspect that there is severe geomagnetic interference in surroundings.

You can check the geomagnetic calibration status by those AT commands :

Send the command `AT + INFO = HSI`, and the module will print the current status of the geomagnetic calibration system:

Received Message

valid: 13

fiterr: 0.026630

bin\_status: 100%

cal\_cnt: 1

flux: 61.265064

inclination: 63.203552

OK

Clear

Send AT

AT+INFO=HSI

Write

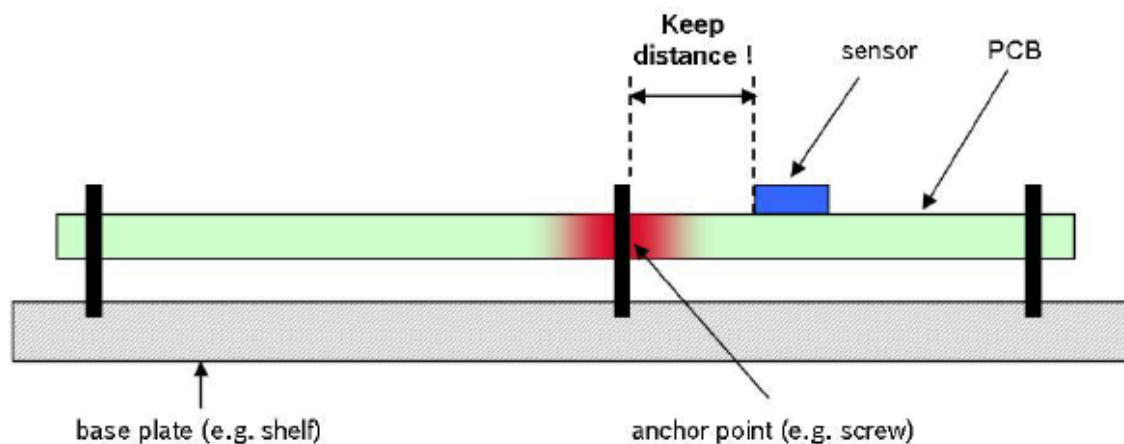
The Showing of HSI Parameter	Meaning	Description
valid	Geomagnetic calibration is valid	0: No successful calibration. Non-zero: Calibration parameters already exist.
fiterr	Fitted value of residuals	The smaller the residual error, the better the parameter fitting effect, It's usually below 0.05, which is good enough. If the fitting result is always > 0.1, meaning that there is severe geomagnetic interference.
bin_status	Acquisition progress of current geomagnetic data	This represents the latest geomagnetic data collection progress, as a percentage of 0-100%. While it reaches 100%, the geomagnetic calibration parameters will be fitted.
cal_cnt	Number of successful calibrations	The accumulated number of times that fitter has calibrated. This number is saved after powering off.
flux	Geomagnetic field strength estimated by the fitter	Estimated geomagnetic field strength in "uT" by the most recent fitter

The Showing of HSI Parameter	Meaning	Description
inclination	Geomagnetic inclination estimated by the fitter	Magnetic dip estimated in "°" by the most recent fitter

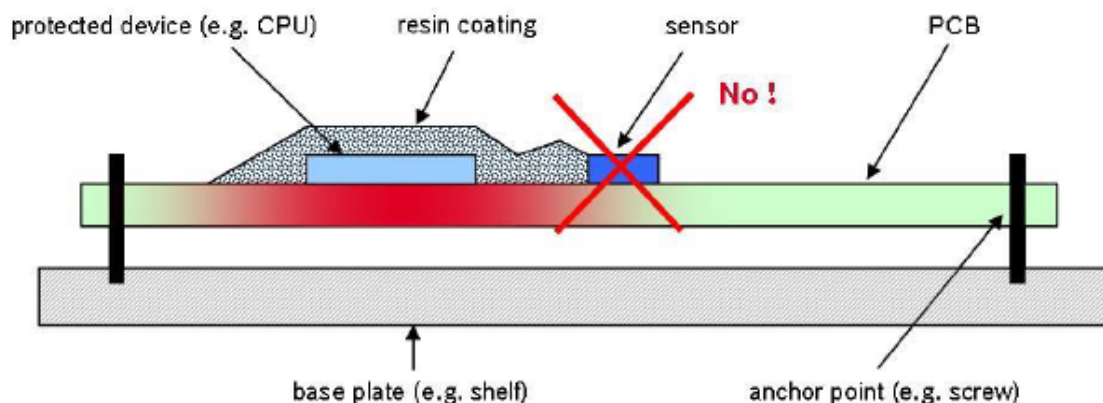
- The estimator can automatically collect data online and dynamically fit the geomagnetic calibration parameters. However, if the geomagnetic environment changes (such as switching to another room or changing between indoor and outdoor), we suggest that you recalibrate.

## Hardware Installation and Welding

1. The installation position should be far away from the easy deformation point of the PCB, as far as possible from the edge of the PCB (> 30mm) and the screw hole of PCB (> 10mm).



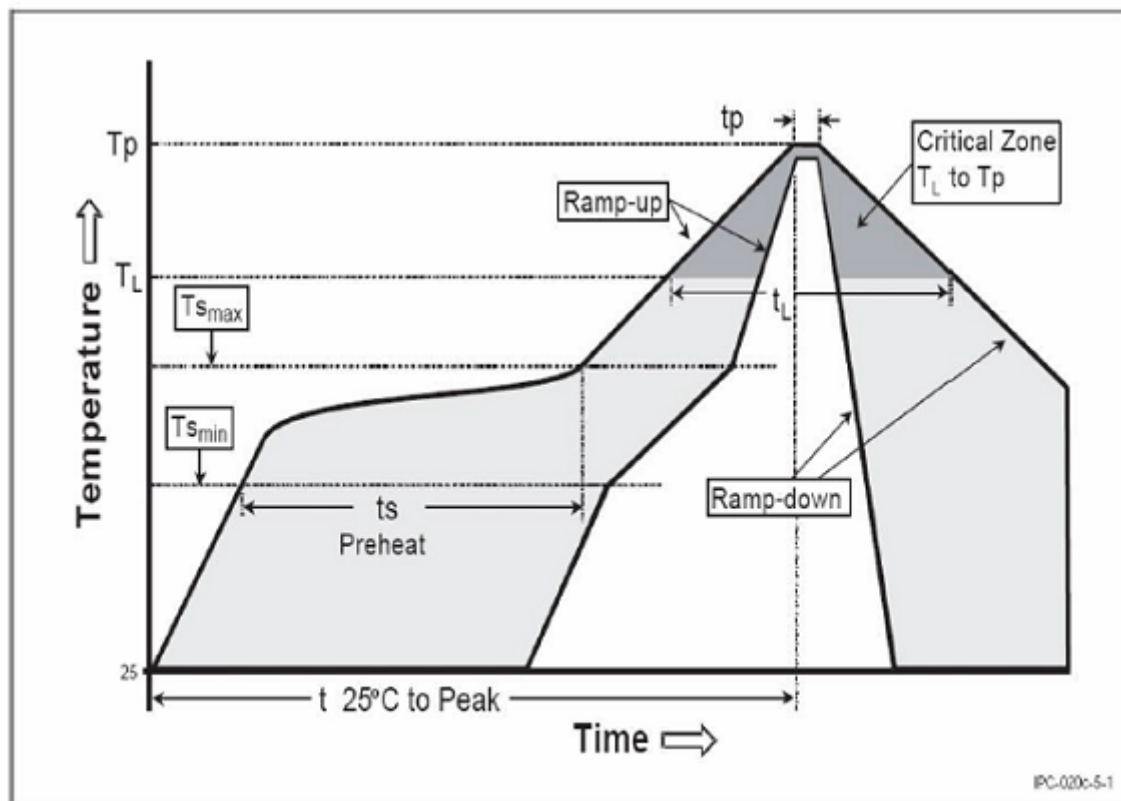
2. The installation location should be far away from strong magnetic devices, such as motors, speakers and other strong magnetic devices.
3. Since MEMS sensors are very sensitive to stress on PCB board, we suggest you that solder the modules by hand, instead of using reflow soldering, otherwise the sensor performance will be affected. If reflow soldering must be used, you should notice that the solder paste is printed on the screen with a printing squeegee, so that the solder paste is leaked onto the PCB through the screen opening. In order to ensure the quality of reflow soldering, it is recommended that the thickness of the stencil corresponding to the pad be 0.18mm.
4. The assembled PCB must not be cleaned with an ultrasonic cleaner.
5. Do not use plastic seals or spray paints on this product. Those will change stress in sensor and affect its performance.



6. The recommended furnace temperature curve for reflow is as follows :

Profile Feature		Pb-Free Assembly
Average Ramp-Up Rate ( $T_{s_{max}}$ to $T_p$ )		3° C/second max.
<b>Preheat</b> – Temperature Min ( $T_{s_{min}}$ ) – Temperature Max ( $T_{s_{max}}$ ) – Time ( $t_{s_{min}}$ to $t_{s_{max}}$ )		150 °C 200 °C 60-180 seconds
Time maintained above: – Temperature ( $T_L$ ) – Time ( $t_L$ )		217 °C 60-150 seconds
Peak/Classification Temperature ( $T_p$ )		260 °C
Time within 5 °C of actual Peak Temperature ( $t_p$ )		20-40 seconds
Ramp-Down Rate		6 °C/second max.
Time 25 °C to Peak Temperature		8 minutes max.

**Note 1:** All temperatures refer to topside of the package, measured on the package body surface.



Reference : [https://ae-bst.resource.bosch.com/media/\\_tech/media/application\\_notes/BST-MAS-HS000.pdf](https://ae-bst.resource.bosch.com/media/_tech/media/application_notes/BST-MAS-HS000.pdf)

## Definition of Reference Frame

This product uses **right-hand** (cartesian) coordinate system. The output of quaternions and Euler angles are the rotation from the sensor coordinate system to the inertial coordinate system (which is also called world coordinate system).

The rotation order of Euler angles is ZYX (Z axis first, then Y axis, and finally X axis), which is specifically defined as follows :

- Rotate around Z axis : Yaw, phi ( $\psi$ ) . The range is -180° to 180°
- Rotate around Y axis : Pitch, theta ( $\theta$ ) . The range is -90° to 90°
- Rotate around X axis : Roll, psi ( $\phi$ ) . The range is -180° to 180°

This product uses (North-West-Up, NWU) coordinate system, which is defined as follows :

- Positive X axis points to north

- Positive Y axis points to west
- Positive Z axis points to the sky

When using the NWU system and the module is simulated as an aircraft, the X axis should be considered as heading direction. When the coordinate system of sensor and world are coincide, the ideal output of the Euler angles should be :

- Pitch = 0 °, Roll = 0 °, Yaw = 0 °

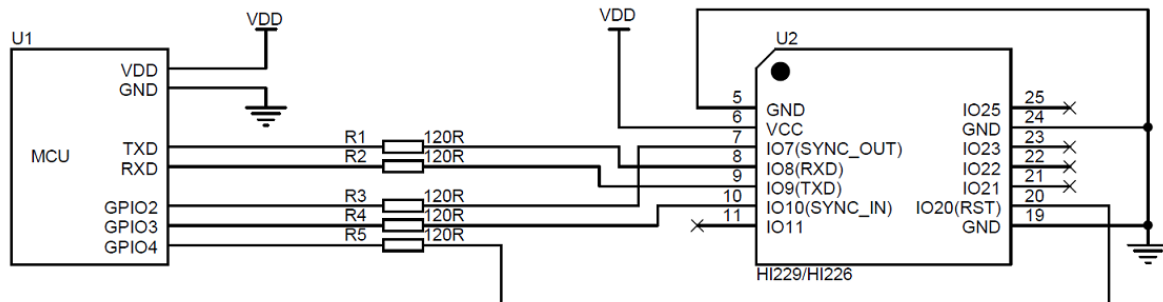
## Application Guide

### Connection Between Module and PC

It is recommended to use an evaluation board to connect with a PC. The evaluation board has on-board USB power supply and Micro-USB to serial port converter. You can use the evaluation software on the PC for module performance testing directly. Please read the appendix A for more details.

### Connection Between Module and Micro Controller

The module and MCU are connected through a TTL-level serial port. We suggest that the RST pin of the module be connected to the MCU's GPIO for MCU to force reset the module.



### Notice

1. If you do not use the synchronous input (SYNC\_IN) and synchronous output function (SYNC\_OUT), do not connect SYNC\_IN and SYNC\_OUT.
2. Keep the 120 ohm resistor to facilitate debugging and prevent a mismatch between MCU resetting and the module. Removing the resistor will not affect its operation. However, it is recommended to keep it.
3. The voltage range of VCC is specifically explained in the user guide.

## Protocol of Serial Communication

### Format of a Packet

For more applications, we provide data analysis functions by C and C# in supporting resources. After the module is powered on, the packets output rate is set by default at 100Hz (factory default output rate). The format of data packet is described as follows :

Field	Syncing frame header	Frame type	Frame length	CRC16	Data in a frame
name	PRE	TYPE	LEN	CRC	REG_ADDR(N) + DATA(N)
size (byte)	0	1	2	2	variable (1-64)
shift (byte)	0	1	2	4	6

Field (hex)	Syncing frame header	Frame type	Frame length value	CRC16 check code	Data in a frame
type	uint8_t	uint8_t	uint16_t	uint16_t	-

- PRE  
It's fixed at 0x5A.
- TYPE  
It's fixed at 0xA5 representing a data frame.
- LEN  
The length of data field in a data frame. The maximum of a data frame is 256 bytes LSB (low byte first), and the length only includes of the real data, not including PRE,TYPE,LEN,CRC numeric field.
- CRC  
16-bit CRC checksum of all the other data and LSB[^LSB] in a frame, except the CRC itself. CRC implementing functions is presented as follows :

```

1  /*
2     currentCrc: previous crc value, set 0 if it's first section
3     src: source stream data
4     lengthInBytes: length
5  */
6  static void crc16_update(uint16_t *currentCrc, const uint8_t *src, uint32_t lengthInBytes)
7  {
8     uint32_t crc = *currentCrc;
9     uint32_t j;
10    for (j=0; j < lengthInBytes; ++j)
11    {
12        uint32_t i;
13        uint32_t byte = src[j];
14        crc ^= byte << 8;
15        for (i = 0; i < 8; ++i)
16        {
17            uint32_t temp = crc << 1;
18            if (crc & 0x8000)
19            {
20                temp ^= 0x1021;
21            }
22            crc = temp;
23        }
24    }
25    *currentCrc = crc;
26 }

```

- REG\_ADDR and DATA  
A frame of data can be composed of multiple data packets. Each data packet contains two parts: register address (REG\_ADDR) and register data (DATA). The register address determines the type and length of the data, and DATA is the content of register data. Supported list of registers in the module is described as follows :

Register address	Bytes in register	Name	Unit
0x90	1	user ID of the module	N/A
0xA0	6	acceleration	0.001G <sup>1</sup>
0xA5	6	linear acceleration	0.001G
0xB0	6	angular velocity	0.1°/s
0xC0	6	strength of magnetic field	0.001Gauss
0xD0	6	Euler angles (as integer)	1°
0xD9	12	Euler angles (as float/double)	1°
0xD1	16	quaternion	N/A
0xF0	4	air pressure	Pa
0x71	128-256 bytes (variable)	Quaternion collection from wireless nodes	N/A
0x72	48-96 bytes (variable)	Euler angles collection from wireless nodes	1°
0x75	48-96 bytes (variable)	acceleration collection from wireless nodes	0.001G <sup>1</sup>
0x78	48-96 bytes (variable)	angular velocity collection of wireless nodes	0.1°/s
0x61	3	extensive identification of the wireless data frame	N/A

- 0x90  
user ID of the module
- 0xA0  
Raw acceleration of the sensor, outputted as int16, and three axes in total. Each axis occupies 2 bytes, so the total of X, Y, Z axes is 6 bytes, and LSB.
- 0xA5  
Linear acceleration value without gravity in geographic coordinate system, outputted as int16. There are 3 axes, X, Y, and Z, each axis occupies 2 bytes, so the total is 6 bytes, and LSB.
- 0xB0  
Angular velocity of the sensor, outputted as int16. There are 3 numbers for 3 axes, X, Y, and Z, and each number occupies 2 bytes, so the total of them is 6 bytes, LSB.
- 0xC0  
The strength of magnetic field measured by the sensor, outputted as int16. There are numbers in 3 axes, X, Y, and Z, and each number occupies 2 bytes, so the total is 6 bytes, LSB.
- 0xD0  
Euler angles of the sensor, outputted as int16. There are 3 numbers, , and the order is Pitch-Roll-Yaw for 3 axes, X, Y, and Z, . Each number occupies 2 bytes, LSB. The values of Roll and Pitch you received need to be divided by 100 , and Yaw needs to be divided by 10 to get the true angles :
  - ex. When you receive Yaw = 100, the heading angle is 10 °.
- 0xD9  
Euler angles of the sensor, outputted as float. There are 3 numbers, Pitch, Roll and Yaw for 3 axes, X, Y, and Z. Each number occupies 4 bytes (float), LSB.

- 0XD1  
Quaternion of the sensor, outputted as float. The data contains four number, which is put in order of W-X-Y-Z. Each of the number occupies 4 bytes (float), so the total size of quaternion is 16 bytes, and LSB.
- 0XF0  
Air pressure. Only works for products with pressure sensor.
- 0x71  
**Only support HI221GW(receiver).** The collection of quaternions from wireless nodes. A frame consists of a series of quaternions from the nodes, in order of the **user ID** you set. For example, you set nodes ID from 0 to 5, there will be 6 nodes totally. Each node occupies 16 bytes, and consists of a quaternion that is W, X, Y, and Z. Every value is stored in the float type, and each float occupies 4 bytes, and LSB.
- 0x72  
**Only support HI221GW(receiver).** The collection of Euler angles of wireless nodes. A frame consists of a series of Euler angles from the nodes, in order of the **user ID** you set. For example, you set nodes ID from 0 to 5, there will be 6 nodes totally. Each node occupies 6 bytes, and consists of 3 integers(int16) in order of Pitch-Roll-Yaw, and each integer occupies 2 bytes, and LSB. The values of Roll and Pitch you received need to be divided by 100, and Yaw needs to be divided by 10 to get the true angles :
  - ex. When you receive Yaw = 100, the heading angle is 10 °
- 0x75  
**Only support HI221GW(receiver).** The collection of accelerations from wireless nodes. This section consists of a series of accelerations from the nodes, in order of the **user ID** you set. Each node contains 3 **int16\_t**, in order of X, Y, and Z. Note that an **int16\_t** occupies 2bytes, and LSB.
- 0x78  
**Only support HI221GW(receiver).** The collection of angular velocities from wireless nodes. This section consists of a series of angular velocities from the nodes, in order of the **user ID** you set. Each node contains 3 **int16\_t**, in order of X, Y, and Z. Note that an **int16\_t** occupies 2bytes, and LSB.
- 0x61  
**Only support HI221GW(receiver).** Get extensive identification of the wireless data frame, 3 bytes in total.

Bytes offset in data frame extension identification	Value	Description
0	-	N/A
1	GWID	GWID of a receiver
2	CNT	the count of nodes contained in this frame : 1-16

## Factory Default Register

The register data carried in one frame by factory default is defined as follows :

HI226/HI229:

Order	Data packet	Description
1	0x90	user ID of module
2	0xA0	accelerations
3	0xB0	angular velocities
4	0xC0	strength of magnetic field
5	0xD0	Euler angles as integer
6	0xF0	air pressure

HI221GW(wireless receiver of nodes):



Order	in Register	Description
1	0x71	quaternions
2	0x75	angular velocities

## Example of Data Structure in a Frame

Let's assume that A0, B0, D0 are in a frame of some output data. Use the serial assistant to sample a frame of data, and find the following value:

5A A5 15 00 A9 8B A0 EA FF D0 03 45 FF B0 00 00 00 00 00 00 D0 87 00 6F 27 F5 FF

where :

5A A5 is frame header.

15 00 is the length of data field :  $(0x00 \ll 8) + 0x15 = 21$

A9 8B is the checksum of CRC :  $(0x8B \ll 8) + 0xA9 = 0x8BA9$

- A0 EA FF D0 03 45 FF are the accelerations, A0 is the register address of accelerations. Therefore, the linear accelerations of 3 axes are :

$\text{AccX} = (\text{int16\_t})((0xFF \ll 8) + 0xEA) = -22$

$\text{AccY} = (\text{int16\_t})((0x03 \ll 8) + 0xD0) = 976$

$\text{AccZ} = (\text{int16\_t})((0xFF \ll 8) + 0x45) = -187$

- B0 00 00 00 00 00 00 are angular velocities, B0 is the register address of angular velocities. From these values, we find that angular velocities around 3 axes are all zero.
- D0 87 00 6F 27 F5 FF are Euler angles, D0 is the register address of Euler angles. From these values, we find that :

$\text{Pitch} = (\text{int16\_t})((0x00 \ll 8) + 0x87) / 100 = 1.35^\circ$

$\text{Roll} = (\text{int16\_t})((0x27 \ll 8) + 0x6F) / 100 = 100.95^\circ$

$\text{Yaw} = (\text{int16\_t})((0xFF \ll 8) + 0xF5) / 10 = -1.1^\circ$

- Calculate the CRC :

Remember that the frame of data is received and stored in the buffer of C language `uint8_t` array :

```

1  uint16_t payload_len;
2  uint16_t crc;
3
4  crc = 0;
5  payload_len = buf[2] + (buf[3] << 8);
6
7  /* calculate 5A A5 and LEN filed crc */
8  crc16_update(&crc, buf, 4);
9
10 /* calculate payload crc */
11 crc16_update(&crc, buf + 6, payload_len);

```

After calculating, the CRC checksum is 0x8BA9, same as the CRC value carried in the frame. The check result is correct

## General AT Command

The Module parameters can be configured and checked by AT commands. AT commands always start with the ASCII code AT, followed by the control characters, and end with a carriage return and linefeed `\r\n`. You can use any serial debugging assistant for testing.

Mode  
☒ 6 - Axis  
☐ 9 - Axis

Action  

Module information

Reset

Receive at 50Hz

Start receiving

Stop receiving

Output Config  
☒ GWID(90)  
☒ Accelerations(A0)  
☒ Angular velocities(B0)  
☒ Magnetic field(C0)  
☒ Euler angles(D0)  
☒ Quaternion(D1)  
☐ Air pressure(F0)

Write config

Magnetometer Calibration  

Calibrate

About geomagnetic field calibration:

1. Make sure there is no electromagnetic equipment around.
2. Click "Calibrate".
3. Rotate around any axis or 8-digit path until the picture shows a full circle.
4. Click to finish the calibration.
5. Restrat the module and software, and test again.

Protocol Description:  
5A

Received Message  

HI221 1.0.4 build Sep 25 2019  
2007 - 2019 Copyright by HiPNUC  
MODE: 0(6 AXIS)  
ID: 2  
SERIAL: FC670D3C  
ODR: 100Hz  
new packet items:  
ID [0x90]  
AccRaw [0xA0]  
GyrRaw [0xB0]  
MagRaw [0xC0]  
EularAngle[0xD0]  
Quaternion[0xD1]  
OK

Clear

Send AT

AT+SETPTL=90,A0,B0,C0,D0,D1

Write

Exit Setting

General AT Commands :

Command	Function	Configure once (N) / Configure permanent after restart (Y)
AT+ID	Set a user ID for the module	Y
AT+GWID	Assign an ID to the wireless network domain (for wireless product)	Y
AT+URFR	Rotate the coordinate system of the module	Y
AT+INFO	Print out the information of module	N
AT+ODR	Set the output frequency for a frame of module data	Y
AT+BAUD	Set Baud for serial port	Y
AT+EOUT	A switch for the output data	N
AT+RST	Reset the module	N
AT+TRG	Trigger the module to output a frame	N
AT+SETPEL	Configure the content in a frame	Y
AT+MODE	Set an operation mode of the module	Y

## AT+ID

Set a user ID for the module

ex. AT+ID=1

## AT+GWID

Only support HI221. HI221GW (receiver) and HI221 (node) have GWID attribute, you can assign a number of GWID for specific radio frequency by AT+GWID command, and only when both node and the receiver are in the same GWID, they can communicate with each other. GWID is just like a wireless network domain. If you're using more than one receiver to establish multiple star networks, you have to assign different GWID to each receiver °

ex. set GWID=3 for a receiver, meanwhile there are three nodes are individually set to 0,1, and 2. Let them be able to communicate with the receiver.

Command for

receiver : AT+GWID=3

node 0 : AT+GWID=3 AT+ID=0

node 1 : AT+GWID=3 AT+ID=1

node 2 : AT+GWID=3 AT+ID=2

## AT+URFR

In some cases the IMU sensor needs to be installed tilted or vertically. This command helps you to rotate the coordinate system of the sensor :

ex. AT+URFR=C00,C01,C02,C10,C11,C12,C20,C21,C22

where  $C_{nn}$  support float and double type.

$$\begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_U = \begin{bmatrix} C00 & C01 & C02 \\ C10 & C11 & C12 \\ C20 & C21 & C22 \end{bmatrix} \cdot \begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_B$$

where  $\begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_U$

are the measurement data after coordinate system correction, and  $\begin{Bmatrix} X \\ Y \\ Z \end{Bmatrix}_B$  are the measurement data

before coordinate system calibration.

Some examples of commands :

- Rotate N° around original X or Y or Z axis as a new coordinate system
  - 90° around original X axis : AT+URFR=1,0,0,0,0,1,0,-1,0
  - -90° around original X axis : AT+URFR=1,0,0,0,0,-1,0,1,0
  - 180° around original X axis : AT+URFR=1,0,0,0,-1,0,0,0,-1
  - 90° around original Y axis : AT+URFR= 0,0,-1,0,1,0,1,0,0
  - -90° around original Y axis : AT+URFR= 0,0,1,0,1,0,-1,0,0
  - 180° around original Y axis : AT+URFR= -1,0,0,0,1,0,0,0,-1
- Factory reset : AT+URFR=1,0,0,0,1,0,0,0,1

## AT+INFO

Print the module information, including model, version, firmware and release date, etc. There are secondary instructions for AT + INFO to achieve more information.

INFO secondary instruction	Function	Example
CAL	Print internal calibration parameters of the module.	AT+INFO=CAL
RF	Print parameters of the wireless product.	AT+INFO=RF
VER	Print details of the firmware version	AT+INFO=VER

### AT+ODR

Set the serial output rate of the module. It can be stored when the power off, and takes effect after restarting the module.

ex. set the rate to 100Hz: AT+ODR=100

### AT+BAUD

Set Baud only in these options : 4800/9600/115200/256000/460800`

ex. AT+BAUD=115200

!!! Notice

- Beware that wrong Baud will result in failure of communication with the module.
- The receiver and module must be in the same Baud.
- Baud must be set to 115200 before you updating the firmware.

### AT+EOUT

A switch of the output from module.

ex.

- Open the serial port of module : AT+EOUT=1
- Close the serial port of module : AT+EOUT=0

### AT+RST

Reset the module.

ex. AT+RST

### AT+TRG

Trigger the module to output a frame. It can cooperate with AT + ODR = 0 to trigger a single output °

ex. AT+TRG

### AT+SETPEL

Set the output protocol:

The content in a frame of data can be configured using AT commands, by following the format:

AT+SETPTL=<ITEM\_ID>,<ITEM\_ID> . . .

A frame of data can contain up to 8 packets.

ex. Configure the module to output acceleration, angular velocity, Euler angle and quaternion in the format : AT+SETPTL=A0,B1,D0,D1

Mode

☒ 6 - Axis
☐ 9 - Axis

Action

Module information
Reset
Receive at 50Hz
Start receiving
Stop receiving

Output Config

☒ GWID(90)
☒ Accelerations(A0)
☒ Angular velocities(B0)
☒ Magnetic field(C0)
☒ Euler angles(D0)
☒ Quaternion(D1)
☐ Air pressure(F0)

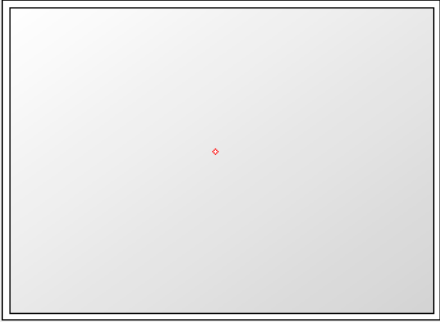
Write config

Magnetometer Calibration

Calibrate

About geomagnetic field calibration:

1. Make sure there is no electromagnetic equipment around.
2. Click "Calibrate".
3. Rotate around any axis or 8-digit path until the picture shows a full circle.
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Protocol Description:  
5A

Received Message

HI221 1.0.4 build Sep 25 2019  
2007 - 2019 Copyright by HiPNUC  
MODE: 0(6 AXIS)  
ID: 2  
SERIAL: FC670D3C  
ODR: 100Hz  
new packet items:  
ID [0x90]  
AccRaw [0xA0]  
GyrRaw [0xB0]  
MagRaw [0xC0]  
EularAngle[0xD0]  
Quaternion[0xD1]  
OK

Clear

Send AT

AT+SETPTL=90,A0,B0,C0,D0,D1

Write

Exit Setting

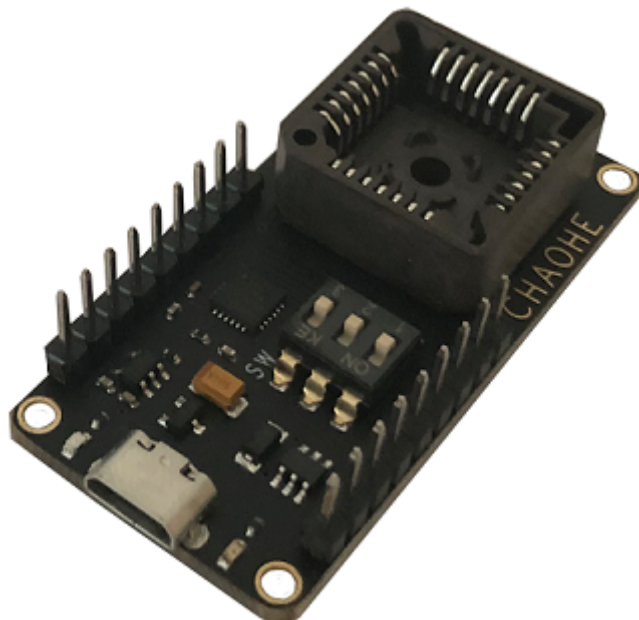
## AT+MODE

Set the operation mode for the module.

ex.

- Set the module to work in 6-axis mode (without magnetic calibration) AT+MODE=0
- Set the module to work in 9-axis mode (will calibrate the heading angle by geomagnetic field sensor)  
AT+MODE=1

## Appendix A - Evaluation Board



### Overview:

This evaluation board provides a quick way to evaluate our IMU modules, which contains those features :

- An on-board Micro-USB interface, which provides USB to serial port communication, and supplies power to this platform.
- Supplying 3.3V 100mA to IMU module via on-board CP2104 USB-UART chip.

## Getting started:

1. Install "CP2104 USB-UART" driver from our website.
2. Connect your Micro-USB cable on the evaluation platform, and the other end to an available USB port on the host PC.
3. Run "Uranus" program on host PC, and choose the serial port you connected.
4. The evaluation board will output packets via 115200-N-8-N-1 by default.

## Remove the product from the evaluation board:

The IMU module is embedded in the PLCC-28 slot by default. To remove the module, please follow these steps:

- Power off and prepare a screwdriver or tweezers.
- Pry out the module from the PLCC socket, or eject it from the circular hole on the back.

## Notice

- The evaluation board can only be used for simple evaluation for performance of IMU module. The USB interface is not designed for intended, industrial or high-motion scenes, and we don't recommend using evaluation board directly in such conditions if you need reliability.
- When using the evaluation board, the serial port of the module is connected to the USB-UART chip. Notice that UART can only communicate one-to-one. Do NOT connect the IMU module or the TX/RX pin to other serial device. Otherwise it will physically damage both evaluation board and IMU module.

## Appendix B - Conversion Between Quaternion and Euler Angles

### Basic conceptions of quaternion

Quaternion is a number system that extends the complex numbers, representing a point in four-dimensional space :  $q \in \mathbb{R}^4 = \mathbb{H}$

This table shows several representation of quaternions :

in complex numbers	in vector	representation 1	representation 2
$q = q_0 + iq_1 + jq_2 + kq_3$	$q = [q_0, \mathbf{q}] = \left[ q_0, \begin{pmatrix} q_1 \\ q_2 \\ q_3 \end{pmatrix} \right]$	$q = [q_0, q_1, q_2, q_3]$	$q = [q_w, q_x, q_y, q_z]$

How to multiply basis elements :

$$i^2 = j^2 = k^2 = ijk = -1$$

$$ij = k = -ji, \quad jk = i = -kj, \quad ki = j = -ik$$

How to multiply two quaternions :

$$\mathbf{p} \otimes \mathbf{q} = \begin{bmatrix} p_w q_w - p_x q_x - p_y q_y - p_z q_z \\ p_w q_x + p_x q_w + p_y q_z - p_z q_y \\ p_w q_y - p_x q_z + p_y q_w + p_z q_x \\ p_w q_z + p_x q_y - p_y q_x + p_z q_w \end{bmatrix}$$

An unit quaternion can always be :  $q_R(\alpha, \mathbf{u}) = \left[ \cos \frac{\alpha}{2}, \sin \frac{\alpha}{2} \cdot \mathbf{u} \right]$

where  $\alpha$  is rotation angle ·  $\mathbf{u} \in \mathbb{R}^3$  is rotation axis · and  $\|\mathbf{u}\| = 1$ .

## Conversion between quaternions, rotation matrices, and Euler angles

## Quaternion -> Rotation matrix

$$R_n^b = \begin{bmatrix} q_0^2 + q_1^2 - q_2^2 - q_3^2 & 2(q_1 q_2 + q_0 q_3) & 2(q_1 q_3 - q_0 q_2) \\ 2(q_1 q_2 - q_0 q_3) & q_0^2 - q_1^2 + q_2^2 - q_3^2 & 2(q_2 q_3 + q_0 q_1) \\ 2(q_1 q_3 + q_0 q_2) & 2(q_2 q_3 - q_0 q_1) & q_0^2 - q_1^2 - q_2^2 + q_3^2 \end{bmatrix}$$

## Quaternion -> Euler angles

Rotation matrix, quaternion and Euler angles are three common ways to represent rotation. However, the rotation order must be specified first before you converse **quaternion to Euler angles** and **rotation matrix to Euler angles**. This product uses the "ZYX" rotation sequence which rotates heading angle first, and then the pitch angle, and the last is roll angle.

Formula :

$$\begin{bmatrix} \phi(Roll) \\ \theta(Pitch) \\ \psi(Heading) \end{bmatrix} = \begin{bmatrix} \text{atan2}(2q_2 q_3 + 2q_0 q_1, q_3^2 - q_2^2 - q_1^2 + q_0^2) \\ -\text{asin}(2q_1 q_3 - 2q_0 q_2) \\ \text{atan2}(2q_1 q_2 + 2q_0 q_3, q_1^2 + q_0^2 - q_3^2 - q_2^2) \end{bmatrix}$$

## Euler angles -> Quaternion

From  $s_\phi = \sin \frac{\phi}{2}$ ,  $c_\phi = \cos \frac{\phi}{2}$ , we got :

$$\mathbf{q} = \begin{bmatrix} c_{\phi/2} c_{\theta/2} c_{\psi/2} + s_{\phi/2} s_{\theta/2} s_{\psi/2} \\ -c_{\phi/2} s_{\theta/2} s_{\psi/2} + c_{\theta/2} c_{\psi/2} s_{\phi/2} \\ c_{\phi/2} c_{\psi/2} s_{\theta/2} + s_{\phi/2} c_{\theta/2} s_{\psi/2} \\ c_{\phi/2} c_{\theta/2} s_{\psi/2} - s_{\phi/2} c_{\psi/2} s_{\theta/2} \end{bmatrix}$$

## Euler angles -> Rotation matrix (n->b)

$$R_n^b = \begin{bmatrix} c_\theta c_\psi & c_\theta s_\psi & -s_\theta \\ s_\phi s_\theta c_\psi - c_\phi s_\psi & s_\phi s_\theta s_\psi + c_\phi c_\psi & c_\theta s_\phi \\ c_\phi s_\theta c_\psi + s_\phi s_\psi & c_\phi s_\theta s_\psi - s_\phi c_\psi & c_\theta c_\phi \end{bmatrix}$$

## Rotation matrix (n->b) -> Euler angles

$$\begin{bmatrix} \phi \\ \theta \\ \psi \end{bmatrix} = \begin{bmatrix} \text{atan2}(r_{23}, r_{33}) \\ -\text{asin}(r_{13}) \\ \text{atan2}(r_{12}, r_{11}) \end{bmatrix}$$

## Appendix C - Firmware Upgrade and Factory Reset

This product supports online firmware upgrade. Please pay attention to the official website of Supercore Electronics [www.hipnuc.com](http://www.hipnuc.com) for the latest firmware.

Firmware upgrade steps:

- Get the latest firmware file. The extension of the file is (.hex).
- Connect the module, and run "Uranus". Switch to the firmware upgrade window, and set Baud (Baudrate) to 115200.
- Click "connect" button. If the module information shows successfully, meaning that the system is ready to upgrade.
- Now you can click the file selector (...), and select the firmware with the extension xxx.hex and click to start programming. After the download is completed, there will be a successful notification.
- Close the serial port and restart the module. Now it's upgraded.

<b>File</b> <input type="text" value="ch100\mdk\ch100\ch100.hex"/> .. <input type="button" value="Connect"/>	<b>Message</b> Protocol version: P1.2.0 Program Version:K1.4.0 Maximum packet length:256 Flash size: 480KB DeviceID: 0x52832 Flash sector: 32768 connect successfully
<b>Action</b> <input type="button" value="Write"/> <input type="button" value="Reset"/>	

---

1. 1G = 1x (Local gravitational acceleration) ee