NINE AHRS V4.1 LW Datasheet and User Manual

Revision 0 – Initial Release

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Purpose and Scope

This document describes the NINE AHRS V4.1 LW specifications, functionality, integration requirements, and recommendations. It is designed to guide the user on how to integrate and use the AHRS within a user-defined application. Please note that the documentation might not be complete. If you have any specific questions, please get in touch with Karman Aerospace using the official contact information provided on the website www.karman-aerospace.com. Also, note that the documentation might change over time, and new revisions of this document might have been released. Please first consult the latest version of this documentation before contacting support.

This document is not intended to describe the detailed design or the AHRS. Additional documentation might be available on the support page of the Karman Aerospace website. If you are looking for specific documentation, require additional assistance, or want manufacturer assistance with system integration, contact us using the same support information described above.

Disclaimer

References

Name	Number
DS-009 Pixhawk Connector Standard	-
AHRS V4.1 Dimensions Case	MD-0001

Note: Some references might not be available to the public.

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1. NINE AHRS Datasheet

1.1. Description

The NINE AHRS V4.1 LW is an Attitude Heading Reference System developed for unmanned aerial vehicles (UAVs) with a maximum takeoff weight (MTOW) of 2 to 500 kg. The AHRS collects inertial data (Accelerations and Rotation Rates) using an Inertial Measurement Unit (IMU) and magnetic field strength data using a magnetometer. This data is fused together to provide an accurate orientation solution of the aircraft to its flight control computers and other systems. The AHRS outputs Pitch, Roll and Heading Angles as well as inertial sensor data and magnetic field strength. As a standalone unit is capable to accurately determine vehicle attitude and serve as a sensor data source. Other systems rely on accurate attitude data to provide flight control, system stabilization or data recording. The NINE AHRS LW series is a low-cost device specifically designed for light UAVs. For professional applications refer to the NINE AHRS PRO or Karman Aerospace directly.

1.2. Features

- 5V Power Supply @ 200mA max.
- Mass below 50 grams
- Output Data Rates up to 1000 Hz
- Orientation Solution as Pitch, Roll and Heading Angles
- Orientation Solution as Quaternion
- Raw IMU and Magnetic Field Strength Data Output
- Data Recording on micro-SD Card
- Configurable Sensor Scale (up to +-16g acceleration and +-2000 degrees/s rotation rate)
- CAN Bus 2.0B Interface with DroneCAN protocol
- UART Interface
- USB 2.0 (USB Type-C Connector) as Configuration Interface
- Heading Accuracy up to +-1.0 degree
- Custom Solution possible

1.3. Electrical Characteristics

Parameter	Notes	Min.	Typ.	Max.	Unit
V_{in}	DC Input Voltage	4.5	5	5.5	V
V_{diff}	DC Input Voltage difference between simultaneous power supplies			500	mV
I_{in}	Input Current, V_{in} = 5V			200	mA
V_{PP} peak pulse voltage	IEC61000-4-2 level 4 air discharge USB Port protection		15		kV
	IEC61000-4-2 level 4 contact discharge USB Port protection		15		
	MIL STD883G-METHOD 3015-7 USB Port protection		25		

1.4. Performance

Parameter	Notes	Min.	Typ.	Max.	Unit
Heading Accuracy	Calibrated device HFE and SFE enabled	+-2.0	+-1.0		°
Acceleration Scale		+-2		+-16	g
Rotation Rate Scale		+-125		+-2000	°/s
Acceleration Resolution	Hardware Revision 2 (12 bit)	0.0078125		0.00097657	g
	Hardware Revision 3 (16 bit)	0.0004883		0.00006104	
Gyroscope Resolution		0.06103516		0.0038147	°/s
Output Data Rate		1		1000	Hz
Output Data Rate Jitter	Output Data Rate = 1000 Hz, Dynamic Time Compensation enabled, No SD-Card logging		0.1	0.5	%
Orientation Solution Drift	Calibrated device HFE and SFE enabled Static and dynamic applications			1	°/h
Alignment Time	power off to stable orientation solution Static vehicle			5	s
Temperature Range		-40		80	℃
Orientation Drift due to Temperature			+-0.07		°/K

1.5. Physical Dimensions

Dimension	Notes	Value	Unit
Length		48.4	mm
Width		68	mm
Height		15	mm
Mass		≤ 50	g
Recommended mounting screws	Flange mount hole diameter = 3.2 mm	M3	N.A.
Mounting hole grid		35 x 58	mm

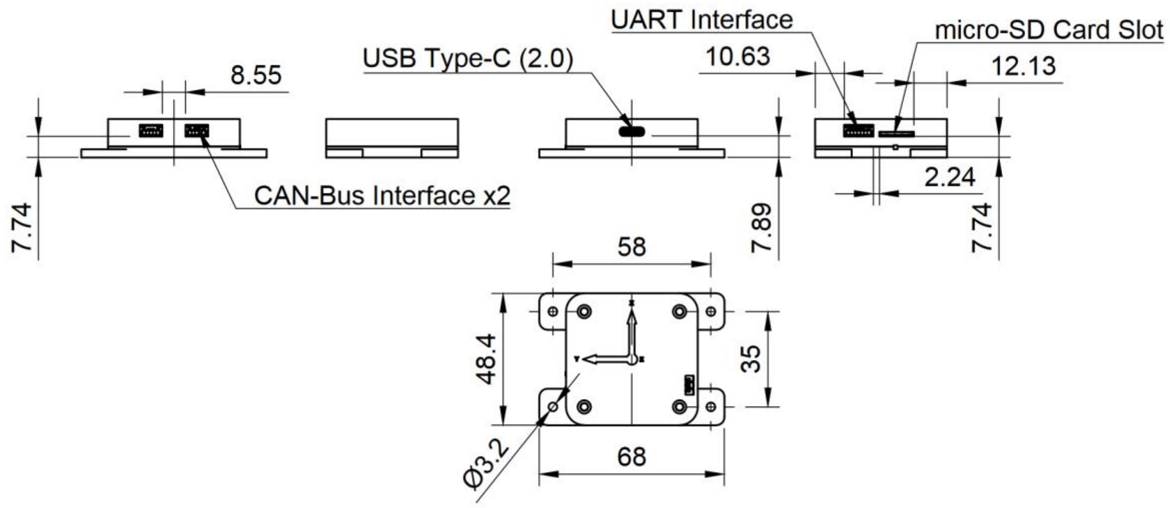


Figure 1 – AHRS Dimension and Interfaces (MD-0001)

1.6. Known Limitations

This subsection tracks known limitations of the NINE AHRS at the time of release of the document. These limitations are known to Karman Aerospace. If new system limitations appear within the scope of the intended functionality of the AHRS, this list can be extended. These limitations should be considered for system integration. Note that the latest version of this document might contain more or different limitations. Each limitation is listed with a recommendation to mitigate the issue and an action that Karman Aerospace is working on to eliminate the limitation.

Limitation 1: Software Limitation – Data Logging to SD-Card at high Output Data Rates

Description:

Logging data to the SD card at output data rates above 100Hz will lead to unstable output streams and lost packets.

Recommendation:

Only use SD card data logging with an ODR setting of 100 Hz or below.

Actions:

We are committed to fixing this issue with the next software version.

Limitation 2: Software & Hardware Limitation – Software Update Capability

Description:

Software updates can't be performed by the user. They have to be uploaded at the factory with hardware access and temporary modification.

Recommendation:

Contact support if you want to update your device.

Action:

We are working on a software tool-based workaround to allow users to update their hardware.

Limitation 3: Software & Hardware Limitation - UART and CAN data rate

Description:

The maximum data rate of the UART and CAN Bus interfaces can impose limits to the maximum output data rate.

Recommendation:

Limit the ODR appropriately if CAN Bus or UART is used.

Action:

We are working on a software update to increase the UART data rate. The CAN Bus will always be limited by its hardware.

2. NINE AHRS User Manual

2.1. Configuration Interface

The NINE AHRS supports changes to its settings using a configuration interface available over USB. The USB interface acts as a Virtual Com Port (VCP) to send and recieve data and commands. All commands are initiated with a "/" character (ASCII: 47). The command has 3 characters with none, one or multiple parameters. Parameters are seperated by a single blank space (" "). Parameters can be float values with a decimal point ("."). This section describes the available commands and what settings can be changes as well as valid parameters and biref setting descriptions.

The AHRS requires a command to enter and leave the configuration mode over USB. Type '/cfg' and press the enter key to enter or leave config mode. Any command other than '/cfg' or '/sav' can only be used in config mode and will be ignored otherwise. The device will suspend data output to any interface while in config mode. Enabling the config mode will start caching settings into a new configuration. Leaving config mode will make this new configuration active. To go back to the old configuration, remove power to the device and don't save the new settings. If you want to save your changes use the '/sav' command when not in config mode. Entering and leaving the config mode without making changes will not have an effect.

When making changes to the settings, make sure to leave the config mode and save the changes made using the '/sav' command. When the changes are not saved, the AHRS will return to the last configuration saved after a power-on reset or reboot. Saving is always done after leaving config mode as changes made in config mode become active when leaving it. Only the active settings are saved. Saving may take up to 500 milliseconds. The settings are written to the onboard flash memory and verified against the active configuration.

The factory reset command will load the factory setting from memory, save them as the user configuration and restart the device. The device will then bootup with the factory settings. The startup mode setting will not have any effect as it will be reset to '1: From memory'.

2.1.1. Command Overview

Command	Setting / Action	Parameters	Note
/cfg	Configuration Mode	None	Enter or leave config mode
/inf	Display current configuration	None	Hardware, Firmware and Configuration Information is displayed
/sav	Save the current configuration	None	Save only after leaving config mode
/odr	Change the output data rate	1x(int) 1-1000	Output data rate in Hz
/dtc	Enabled / Disable Dynamic Time compensation	1x(int) 0-1	0: Disabled, 1: Enabled
/sup	Change the device startup mode	1x(int) 0-2	0: Hard-coded, 1: From memory, 2: From factory settings
/f_a	Change filter alpha parameter	1x(float)	Parameter compensates accelerometer and magnetometer noise (keep >1)
/f_b	Change filter bias parameter	1x(float)	This parameter is the average gyro bias
/f_d	Change filter drift parameter	1x(float)	This parameter is the average gyro drift
/hfe	Enable/Disable HFE or set parameters	1x(int) 0-1 or 3x(float)	0: Disabled, 1 :Enabled, Float Parameters in Gauss (x,y,z)
/sfe	Enable/Disable SFE or set parameters	1x(int) 0-1 or 9x(float)	0: Disabled, 1: Enabled, Float Params in x11,y11,z11,x12... order

Command	Setting / Action	Parameters	Note
/raw	Enable/Disable raw data output	1x(int) 0-1	0: Disabled, 1: Enabled
/int	Enable/Disable output interfaces	4x(int) 0-1	0: Disabled, 1: Enabled (See data output interface setting below)
/fre	Factory reset	None	Resets configuration to factory settings
/can	Change can bus settings	2x(int) or 5x(int)	Change Node ID, Bus Speed and data types (see CAN Bus settings)
/sen	Change sensor scale	2x(int)	Change max acceleration and gyro scales (see Sensor scale settings)
/ios	Change installed orientation setting	1x(int)	Change the orientation mode of the AHRS (see section 3.1.1)

2.1.2. Command "/cfg"

The configuration mode command is used to enter or leave config mode. No changes to device settings can be made when not in config mode. Leaving config mode will make the changes become active.

2.1.3. Command "/inf"

The information command provides data to the user about the hardware and software versions as well as the currently active configuration settings.

2.1.4. Command "/sav"

The save command is used to save the currently active configuration settings to the onboard flash memory of the AHRS. When the device reboots or power is lost and restored, the device will load the user settings from memory during initialization. Saving may take up to 500 milliseconds.

2.1.5. Command “/odr”

The output data rate command is used to change the output data rate (ODR) of the AHRS with a single parameter. The parameter can be an integer between 1 and 1000 and represents the ODR or the device in Hz.

Example: “/odr 500” changes the output data rate to 500 Hz.

2.1.6. Command “/dtc”

The dynamic time compensation setting can be enabled or disabled using this command. It accepts an integer of either 0 (disabled) or 1 (enabled). With dynamic time compensation the AHRS measures its own execution time and adapts to processing jitter and inaccuracies to keep the output data rate and processing interval constant. DTC is enabled by default.

Example: “/dtc 0” disabled the dynamic time compensation.

2.1.7. Command “/sup”

The startup mode of the AHRS can be changed. 3 modes are available: Hardcoded (Fallback), From Memory and Factory settings. The hardcoded mode is automatically used in case the memory fails and settings cannot be read. It is not recommended to be used for normal operation. The default mode is to load settings from memory. It uses the settings saved by the user or factory settings when first powering on the device. The startup mode “Factory settings” can be used to force the AHRS to always use factory configuration. Note that this is not equal to the factory reset.

Example: “/sup 2” changes the startup mode to load factory settings

2.1.8. Command “/f_a”

This command is used to adjust AHRS filter settings. The alpha parameter is used to compensate for accelerometer and magnetic sensor noise. It is not recommended to change this setting. Always keep this value higher than 1. It accepts a single parameter.

2.1.9. Command “/f_b”

This command is used to adjust the AHRS filter settings for gyro bias. This value directly determines the magnitude of gyro bias compensation and represents the average gyro bias value across all axes. It is not recommended to change this setting. It accepts a single parameter.

2.1.10. Command “/f_d”

This command is used to adjust the AHRS filter settings for gyro drift. This value directly determines the magnitude of gyro drift compensation and represent the average gyro drift value across all axes. It is no recommended to change this setting. It accepts a single parameter.

2.1.11. Command "/hfe"

The hard iron magnetic effect compensation command is used to disable or enable HFE compensation and adjust the parameters. The command accepts up to 3 parameters. To disable or enable HFE compensation the command is expecting to be followed by only a single parameter (0 or 1). To adjust the parameters the command is expected to be followed by 3 parameters (3x float / hfe-x, hfe-y, hfe-z). See section 2.5 for details about AHRS calibration.

2.1.12. Command "/sfe"

The soft iron magnetic effect compensation command is used to disable or enable SFE compensation and adjust the parameters. The command accepts up to 9 parameters. To disable or enable the compensation feature the command is expecting to be followed by only a single parameter (0 or 1). To adjust parameters the command is expected to be followed by 9 parameters (9x float). See section 2.5 for details about AHRS calibration.

Example: "/sfe 0" disables soft iron magnetic effect compensation

Example: "/sfe 0.12 0.0123 0.02 0.0113 0.103 0.015 0.009 0.0085 0.1091" changes the sfe parameters.

2.1.13. Command "/raw"

This command is used to disable or enabled raw data output with USB and UART data output. The uavcan.equipment.ahrs.RawIMU data type output over CAN Bus is not modified with this setting. Raw data is always logged to the SD-Card. The command accepts one parameter, either 0 or 1 to disable or enable raw data output. Enabling raw data output will only affect the USB or UART interfaces if they are also enabled using the "/int" command. Raw data will not be sent if these interfaces are disabled in general.

Example: "/raw 1" enables raw data output over USB and UART

2.1.14. Command "/int"

This command use used to enable and disable interfaces and data output. Note that disabling the data output on the USB interface will NOT disable the configuration interface. It is always available. Data output is suspended to all interfaces if the configuration mode is enabled. Data output on the USB interface might cause issues with simple terminal applications in writing and reading commands. The command accepts 4 parameters. Each parameter can be 0 or 1 to disable or enable in sequence:

- USB data Output
- SD-Card data logging
- CAN Bus data output (DroneCAN)
- UART data output

Example: "/int 0 1 1 0" disables USB and UART data output, enables SD-Card logging and CAN Bus data output.

2.1.15. Command "/fre"

This command can be used to reset the AHRS to factory settings. It will overwrite the user saved settings and change the startup mode to boot from memory. The device will reboot after loading the factory settings to the user settings memory location.

2.1.16. Command "/can"

This command is used to change CAN Bus settings. It accepts up to 5 parameters. The first parameter is used to define the setting to change, the second to fifth parameter defines the settings value.

Parameter 1: 1 – Node ID, 2 – Bus Speed in kbit/s, 3 – Data types sent by the AHRS

Parameter 2: Node ID: 1 – 127 CAN Bus node ID

Bus speed: 10, 20, 50, 100, 200, 500, 1000

Parameter 2-5: Data types: 0 or 1 to disable or enable in sequence

ID: 1000; uavcan.equipment.ahrs.Solution

ID: 1001; uavcan.equipment.ahrs.MagneticFieldStrength

ID: 1002; uavcan.equipment.ahrs.MagneticFieldStrength2

ID: 1003; uavcan.equipment.ahrs.RawIMU

Example: "/can 3 0 1 0 1" disables data types 1000 and 1002, enables 1001 and 1003

Example: "can 2 100" changes the CAN Bus speed to 100 kbit/s

Example: "can 1 40" changes the DroneCAN Node ID to 40

2.1.17. Command "/sen"

This command is used to change the sensor scale of the IMU built into the AHRS. The sensor scale of the accelerometer and gyroscope can be adapted to the applications requirements. This allows to either use a large sensor scale or higher precision. The command accepts 2 parameters. The first defines what sensor scale to change, the second is the new scale to use.

Parameter 1: 1 – accelerometer, 2 – gyroscope

Parameter 2: accelerometer: 2, 4, 8, 16 representing +-2, 4, 8, 16 g

gyroscope: 1, 2, 5, 10, 20 representing +-125, 250, 500, 1000, 2000 dps

Example: "/sen 1 8" changes the sensor scale of the accelerometer to +-8g

2.1.18. Command "/ios"

This command is used to change the AHRS installed orientation setting. The AHRS can compensate different orientations and rotates all data outputs to be conform with the defined reference frame. Refer to section 3.1.1 for details about the different orientation modes.

Example "/ios 1" changes the installed orientation setting to the inverted mode.

2.2. CAN Bus

The AHRS supports CAN Bus specification 2.0B. By default, the CAN Bus is operating with the DroneCAN (UAVCANv0) protocol and supports all uavcan.equipment.ahrs message types. The AHRS does not support Timestamping / Time Synchronization. This feature might be added in the future. Use the configuration interface "/can" command (2.1.16) to change settings and the "/int" command (2.1.14) to enable / disable the CAN Bus.

Be aware that the CAN Bust 2.0B is limited to a maximum speed of 1Mbit/s. Including overhead for transmissions the maximum data transfer speed is limited by the number of Nodes and their required transmission bandwidth (Total Bus Load). The following table is intended to give an overview of the relation between output data rate and enabled DroneCAN messages. Please keep in mind that the calculated Bus load is only applicable if the AHRS is the only Node transmitting on the bus. The table is calculated using the maximum size for each message type and a configured Bus speed of 1 Mbits/s.

Output Data Rate	Enabled Drone CAN Messages				bits/s	Bus Load
	Solution – 1000	MFS – 1001	MFS2 – 1002	Raw IMU – 1003		
100	Yes	Yes	Yes	Yes	205600	20.6%
200	Yes	Yes	Yes	–	220800	22.1%
200	Yes	Yes	Yes	Yes	411200	41.1%
500	Yes	–	–	–	328000	32.8%
500	Yes	Yes	–	–	424000	42.4%
500	Yes	Yes	Yes	–	552000	55.2%
500	Yes	Yes	Yes	Yes	1028000	102.8%
750	Yes	–	–	–	492000	49.2%
750	Yes	Yes	–	–	636000	63.6%
750	Yes	Yes	Yes	–	828000	82.8%
750	Yes	Yes	Yes	Yes	1542000	154.2%
1000	Yes	–	–	–	656000	65.6%
1000	Yes	Yes	–	–	848000	84.8%
1000	Yes	Yes	Yes	–	1104000	110.4%
1000	Yes	Yes	Yes	Yes	2056000	205.6%

Bus loads over 70% should be avoided as CAN Bus overhead might introduce additional latency. Additional transmitting nodes will further increase the bus load.

2.2.1. Connector and Physical Characteristics

A standardized connector is used for the CAN Bus interface. The DS-009 Pixhawk Connector Standard defines the CAN connector in detail. The CAN Bus is designed to be looped through the device. Therefore, the AHRS has two connectors. These are connected to one physical CAN Interface. Refer to section 3.2.1 for details on systems integration with CAN Bus.

The physical receptacle used is the SM04B-GHS-TB from the JST GH series of connectors. The counterpart plug is the GHR-04V-S. Cables connected to the AHRS should use this connector. For the pin assignment, refer to DS-009 Pixhawk Connector Standard.

2.2.2. DroneCAN Protocol

The AHRS supports all uavcan.equipment.ahrs messages and sends periodic node status messages at 1 Hz. The supported messages include:

Solution ID-1000

The AHRS solution contains the latest computed attitude solution in quaternion format.

Magnetic Field Strength ID-1001 & Magnetic Field Strength 2 ID-1002

The magnetic field strength message contains the latest measurements directly from the magnetometer of the AHRS and rotated to the AHRS installed orientation reference frame. The newer Magnetic Field Strength 2 message is also supported. Autopilots require one or the other. Both are usually not required as they contain redundant information.

Raw IMU ID-1003

The Raw IMU message contains raw sensor data from the AHRS including lienar acceleration and angular rates. The AHRS omits the integration interval and integrated values of the message type.

For more details about the DroneCAN / uavcan v0 messages refer to the official DroneCAN documentation here: https://dronecan.github.io.

2.3. UART Interface

The UART interface is configured by default to support 8 data bits, no parity, one stop bit and operates at 115200 bits/s. As of software v1.2.0 the AHRS does not allow changes to these parameters. Future software updates might support configurable parameters. Please note that due to the maximum baud rate, the data output rate might have to be reduced to avoid frame loss over this interface. The AHRS generates about 170 bytes per Hz with raw data output enabled and 82 bytes per Hz without. This results in the following data rates:

Output Data Rate	Raw Data Output	UART Interface Load	Notes
10 Hz	disabled	6,560 bits/s (5.7%)	
10 Hz	enabled	13,600 bits/s (11.8%)	
50 Hz	disabled	32,800 bits/s (28.5%)	
50 Hz	enabled	68,000 bits/s (59%)	
84 Hz	enabled	114,240 bits/s (99.2%)	Max with raw data
100 Hz	disabled	65,600 bits/s (56.9%)	
175 Hz	disabled	114,800 bits/s (99.7%)	Max without raw data
100 Hz	enabled	136,000 bits/s (118%)	Not recommended
500 Hz	disabled	328,000 bits/s (285%)	
500 Hz	enabled	680,000 bits/s (590%)	
750 Hz	disabled	492,000 bits/s (427%)	
750 Hz	enabled	1,020,000 bits/s (885%)	
900 Hz	disabled	590,400 bits/s (513%)	
900 Hz	enabled	1,224,000 bits/s (1063%)	
1000 Hz	disabled	656,000 bits/s (569%)	
1000 Hz	enabled	1,360,000 bits/s (1181%)	

2.3.1. Connector and Physical Characteristics

A standardized connector is used for the UART interface. The DS-009 Pixhawk Connector Standard defines the Telemetry connector in detail. The UART interface does not support hardware flow control and therefore leaves RTS and CTS lines floating.

The physical receptacle used is the SM06B-GHS-TB from the JST GH series of connectors. The counterpart plug is the GHR-06V-S. Cables connected to the AHRS should use this connector. For the pin assignment, refer to DS-009 Pixhawk Connector Standard.

2.4. Serial Data Output Protocol

The AHRS is using a proprietary serial data output protocol for UART and USB data output. Each data sent from the AHRS is encoded into a frame format containing a frame start character, data identifier, frame length, payload, and frame end character. The frame length byte is used to verify that the frame end character is not part of the payload and the integrity of the frame. The data identifier is used to determine what data is contained within the payload and how to parse the payload. There is no error checking, parity or CRC built into the protocol to keep the overhead low and the data easy to parse.

2.4.1. Message Framing

The protocol framing is done using single bytes representing in order of transmission, the start of frame character, the id / type of the payload, the frame length, the payload and the end of frame character.

Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	...	Byte n-2	Byte n-1
SOF	Channel ID	Frame length	Payload Byte 0	Payload Byte 1	...	Payload Byte n – 4	EOF
dec 47 or "/"	0-255	n (1-255)			...		dec 0 or "\0"

The start of frame is always a "/" character or 47 ASCII. Parsers can search for this character to detect a start of a frame. Note that the payload might also contain 47 therefore the frame length can be used to determine the end of frame characters position and verify that it is null. The combination of SOF, frame length and EOF ensures that frames are detected correctly. Note that there is a change that the SOF, frame length and EOF values inside a payload also match to indicate a valid frame.

The channel ID value determines the payload content and encoding used to determine what data was transmitted. The ID value can be anything from 0 to 255 although 0 is reserved.

The frame length can be a value from 1 to 255. There are no frames without a payload (n = 0). The frame length includes the start of frame, id, frame length, payload, and end of frame bytes. Any frame has an overhead of 4 bytes. Therefore, the maximum payload length is 255 – 4 = 251 bytes.

The payload bytes include a serialized representation of one or multiple values transmitted. The maximum payload length is 251 bytes. The minimum payload length is 1 byte.

2.4.2. Message Types

Channel Identifier	**Data Type**	**Data Encoding**	**Unit**	**Note**
1	X Acceleration	Single Precision Float (4 bytes)	g	requries raw data output enabled
2	Y Acceleration	Single Precision Float (4 bytes)	g	requires raw data output enabled
3	Z Acceleration	Single Precision Float (4 bytes)	g	requires raw data output enabled
4	X Gyro-Rate	Single Precision Float (4 bytes)	deg/s	requires raw data output enabled
5	Y Gyro-Rate	Single Precision Float (4 bytes)	deg/s	requires raw data output enabled
6	Z Gyro-Rate	Single Precision Float (4 bytes)	deg/s	requires raw data output enabled
7	X Magnetic Field	Single Precision Float (4 bytes)	Gauss	requires raw data output enabled

8	Y Magnetic Field	Single Precision Float (4 bytes)	Gauss	requires raw data output enabled
9	Z Magnetic Field	Single Precision Float (4 bytes)	Gauss	requires raw data output enabled
10	System Status Code	Unsigend Integer 16Bit (2 bytes)	N.A.	
11	Reserved	INACTIVE	N.A.	
12	Data Processing Frequency	Single Precision Float (4 bytes)	Hz	Frequency for data processing
13	Reserved	INACTIVE	N.A.	
14	Reserved	INACTIVE	N.A.	
15	Sensor Temperature	Single Precision Float (4 bytes)	deg C	
16	Pitch	Single Precision Float (4 bytes)	Deg	Limited to +-90 Deg
17	Roll	Single Precision Float (4 bytes)	Deg	Limited to +-180 Deg
18	Magnetic Heading	Single Precision Float (4 bytes)	Deg	Limited to +-180 Deg
19	Orientation Quaternion	4x Single Precision Float (16 bytes)	N.A.	Order: w,x,y,z
20	Acceleration	3x Single Precision Float (12 bytes)	m/s^2	Gravity free acceleration x,y,z
21	Rotation rate	3x Single Precision Float (12 bytes)	deg/s	Computed angular rates x,y,z

2.5. Calibration

The AHRS has two magnetic compensation features built in. HFE compensation is used to remove hard iron offset from the magnetic field strength measurements of the AHRS. Hard iron offset is generated by magnetic metals in proximity of the sensor. The hard iron offset is a linear and directly offsets the measurements. This is constant over time so hard iron offsets can easily be compensated using calibration. Therefore, the AHRS has 3 calibration parameters for HFE. One parameter per sensor axis (x, y, z). Note that the sensor axis might be different from the installed orientation. Therefore, the calibration values configured by the user are automatically rotate from the installed orientation to the sensor reference frame once entered using the configuration interface. This allows the user to perform the calibration in any configured installed orientation mode (/ios command).

The SFE compensation is used to eliminate soft iron magnetic effects on the magnetic field strength values of the AHRS. Soft iron effects usually generated by current flowing through conductors and generating magnetic fields. These fields are not constant over time especially for alternating current (AC). It is recommended to keep wires with large alternating currents away from the AHRS to reduce changing soft iron effects. The constant soft iron effects generated by DC currents or high frequency communication buses can easily be compensated by the AHRS. The majority of these effects are coming from the AHRS's own hardware. Soft iron effects are not linear offsets to the magnetic field strength measurements, but they distort them. In an ideal case the measurements taken in all axes while rotating through the earth's magnetic field, will result in a perfect sphere. This sphere is distorted in all axes by soft iron effects. To reshape the measurements back to a sphere and therefore, remove the soft iron effects, a calibration matrix is used. This matrix contains 3x3 elements and describes the cross axes effects between each of the 3 sensor axes.

Figure 2 shows an example of recorded magnetic field strength data recorded in flight. The red line in the center represents the present HFE offset of the sphere from the 0 point. The sphere looks very close to perfectly spherical but still requires small amounts of SFE compensation. HFE parameters can be found by taking the minimum and maximum values of each axis and calculating the center between them. This is the offset from the 0 point as the min and max should be equally far away from this center. The SFE values can be calculated using spherical fitting coefficients. MATLAB provides a function called magcal which automates this, see https://www.mathworks.com/help/nav/ref/magcal.html.

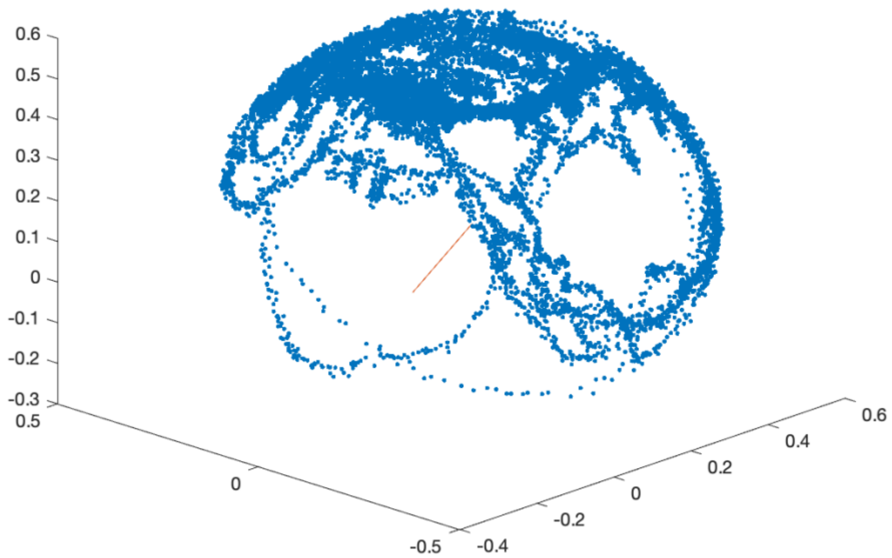


Figure 2 - Magnetic Field Strength Sphere

2.5.1. Factory Calibration

Your AHRS comes factory-calibrated to remove any magnetic distortions from the hardware. The user can always return to factory settings by using the configuration interface's factory reset command. For more information on how to use the configuration interface, refer to section 2.1.

Application-specific magnetic distortions from metal or electromagnetic fields close to the AHRS can generate more interference. Therefore, it is recommended that large current-carrying wires be kept as far away from the AHRS as possible. Metal structures can also interfere with the operation of the AHRS. Output data precision may be degraded by magnetic fields. The magnetic heading output is severely affected by interference. Typically, the data output is offset and distorted.

If the application requires additional calibration because of design requirements, the user can perform calibration using external scripts or tools. The regular data output can be used to calibrate the device.

2.5.2. User Calibration

To calibrate the AHRS, enable raw data output and disable HFE and SFE calibration using the configuration interface. Save the new configuration and record the data output of the AHRS during normal operation. This requires the AHRS to be installed in its final mounting location on the aircraft or host system. The SD-Card can be used to record the flight data. Data written to the SD-Card will always include raw data but still requires configuration to disable calibration and enable the SD-Card logging.

The data recorded can be parsed using common tools like MATLAB or Python. Using these tools, the hard and soft iron calibration values can be determined. Use the HFE and SFE commands of the configuration interface to upload these new calibration values to the ARHS. Re-enable HFE and SFE calibration and save the new configuration.

Please be aware that to determine usable calibration values the AHRS must undergo specific movements/orientations. When using a vehicle, this can be done in flight. It can also be accomplished by rotating the vehicle on the ground. The vehicle must be rotated around all 3 of its axes for 360 degrees or more. This must be done for both the positive and negative axes of the AHRS. In total, six 360-degree rotations are required for an accurate calibration. For aircraft that cannot perform these maneuvers in flight, it is recommended to perform calibration data recording on the ground.

2.6. Software Update

Depending on the installed software version, the user can update the NINE AHRS. All software versions before v1.2.0 do not support software updates from the user. Karman Aerospace is working on a multiplatform software tool to allow users to update their AHRS units. If software updates are required but can’t be performed by the user, Karman Aerospace offers a software update service. Please contact the support team using the contact information on the Karman Aerospace website for more details on the software update service.

AHRS units with software version v1.2.0 installed can be updated by the user. An update requires additional software tools not provided by and are not the intellectual property of Karman Aerospace.

2.6.1. User Update for v1.2.0+

This subsection is reserved for user instructions on updating the AHRS software once newer versions are released. Note that this document might have been revised. For more information on user software updates, refer to the latest version.

3. NINE AHRS System Integration Guide

This guide can be used to integrate the NINE AHRS into your application. Note that the AHRS is intended for autonomous airborne vehicles (UAVs). This documentation focuses only on integration with aircraft. Users can use the AHRS for other applications as required but might find no related information in this guide.

3.1. Mounting

For mounting of the AHRS the integrator must ensure that, the AHRS has a stable power supply and is grounded. Any large current carrying wires must be always kept away from the AHRS to reduce magnetic interference. The AHRS should be calibrated when mounted inside its host system. The AHRS can compensate for some mounting orientations but the axes of the AHRS must align with the body reference frame of the aircraft (see section 3.1.1).

The AHRS does not required any cooling air flow and is cooled through passive radiation. As its power consumption is low, the cooling requirements are usually neglectable.

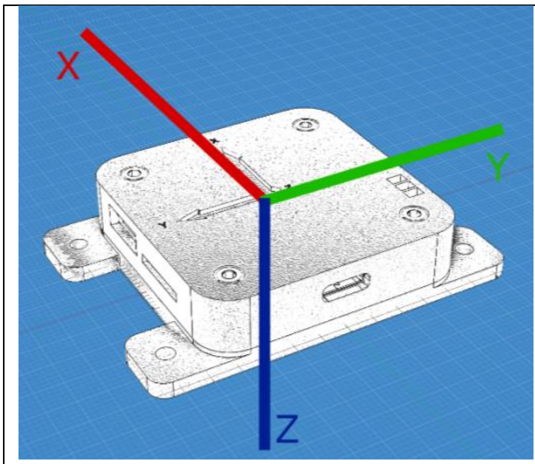
3.1.1. Orientation

The NINE AHRS can be mounted in 6 different orientations about the vehicle's flight axis. These six orientations can be compensated by the built-in orientation correction module. As further software updates are developed, the number of orientations might increase, or user-defined orientations can be compensated for. Please refer to section 2.1.18 for details on how to change this setting. The AHRS will automatically rotate the data output to align with the defined orientation. Note that the axes on the AHRS enclosure are only valid for the upside-down (inverted) mounting orientation. Any additional orientation compensation not available with these settings must be done by the host system.

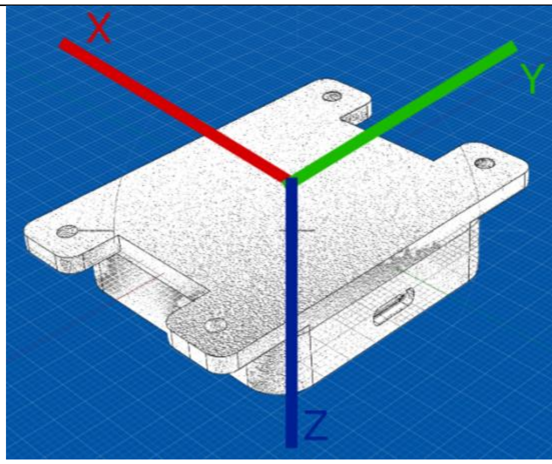
The following six orientation modes are supported as of software version v1.2.0:

Orientation	AHRS Installed Orientation Mode
default (right side up)	Mode 0
inverted (upside down)	Mode 1
right-wall	Mode 2
left-wall	Mode 3
down	Mode 4
up	Mode 5

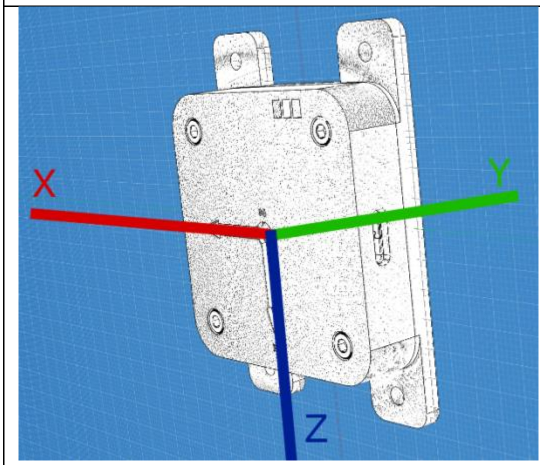
The orientation modes are described in the following pictures, where the X-axis (Red) is in line with the aircraft's forward axis, the Y-axis (Green) faces to the right of the plane, and the Z-axis (Blue) is facing down.



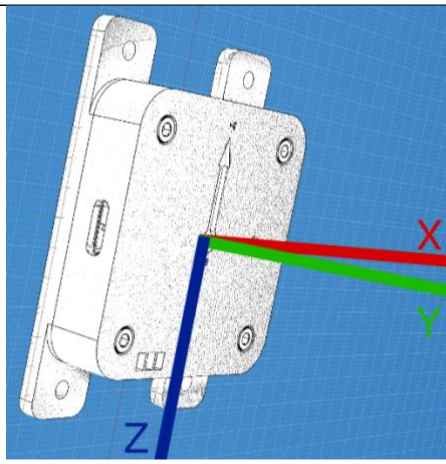
Orientation Mode 0 (default)



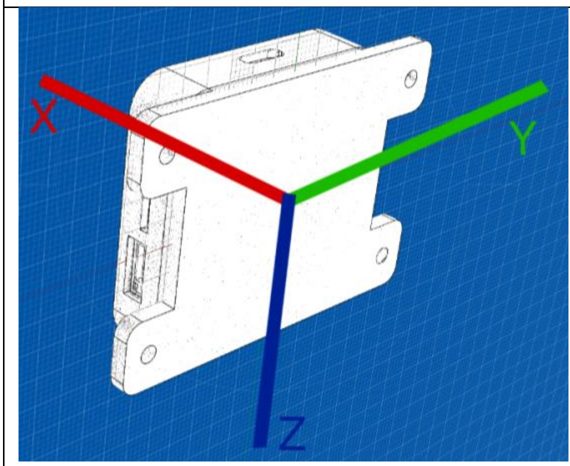
Orientation Mode 1 (inverted)



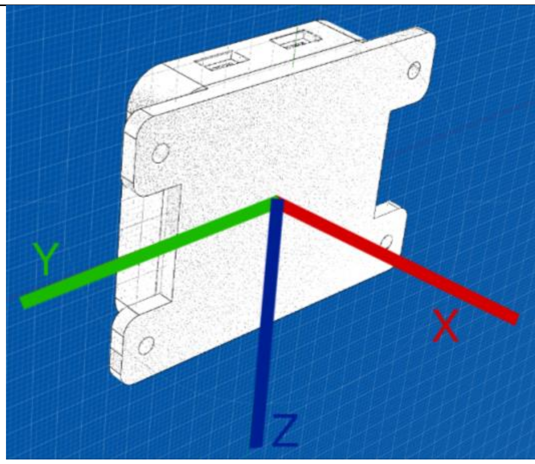
Orientation Mode 2 (right-wall)



Orientation Mode 3 (left-wall)



Orientation Mode 4 (down)



Orientation Mode 5 (up)

3.2. Electrical

The AHRS expects a supply voltage of around 5V. Refer to the electrical characteristics section 1.3 for details. The maximum current draw of the AHRS during normal operation is 200 mA. Should it fail, the AHRS is fused at 1A. This fuse is not resettable and must be replaced after a failure. It is not recommended to replace the fuse without knowing the initial cause for the overcurrent.

The AHRS can be powered over any of the connectors. Power can be provided to the AHRS from multiple connectors simultaneously. This is not recommended when using the USB port to supply or configure the AHRS. The host system must ensure that the power supply voltage of simultaneous connections is stable and within the maximum voltage difference between supplies (V_{diff}) described here 1.3.

3.2.1. CAN Bus Connection

To use the CAN Bus of the AHRS, the following items are required:

- Host system supporting CAN Bus 2.0B
- Host system accepting DroneCAN (uavcan v0) messages
- Connecting the host systems CAN Bus to the AHRS using the connector described here 2.2.1
- Host system CAN Bus is looped through the AHRS
- Host system providing 5V supply voltage over the connector to the AHRS
- Host system providing 1 Watt of power over the connector to the AHRS
- CAN Bus interface is enabled on the AHRS using the configuration interface
- Required DroneCAN messages are enabled using the configuration interface
- CAN Bus termination resistors provided by Host System

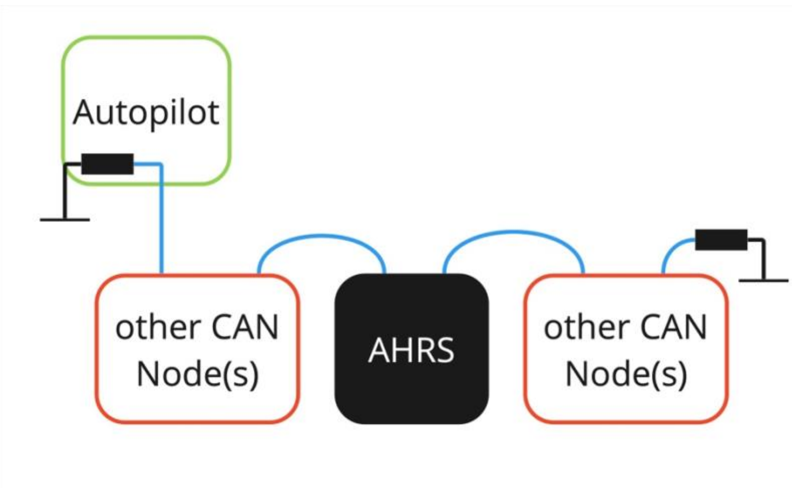


Figure 3 - Common Drone CAN Bus Topology

Refer to section 2.2 for more details about the CAN Bus and a bus load table.

3.2.2. UART Connection

To use the UART Interface of the AHRS, the following items are required:

- Host system supporting UART without hardware flow control
- Host system accepting the proprietary messages defined in section 2.4

- Host system providing 5V supply voltage over the connector to the AHRS
- Host system providing 1 Watt of power over the connector to the AHRS
- UART Interface is enabled on the AHRS using the configuration interface

The UART connection is not intended to be used with a traditional telemetry link as it does not send MAVLINK messages. Some telemetry links forward the data as is and can be used to transmit the serial data of the AHRS when used with an appropriate ground station.

The UART interface does not accept incoming traffic and does not support hardware flow control.

3.3. Integration with ArduPilot

This section is reserved for a future quick guide to integration of the AHRS with a commercial off the shelf autopilot running ArduPilot.

3.4. Integration with PX4

This section is reserved for a future quick guide to integration of the AHRS with commercial off the shelf autopilot running PX4.

Document Revisions and Changes

Author	Revision	Note	Date
DK	0	Initial Release	7th of May 2024

End of Document