PRODUCT SPECIFICATION

VN-100 IMU/AHRS

User Manual

VECTORNAV

CONTENTS

VectorNav Support

Whether you are looking for details on the VN-100 or assistance with your application, a wealth of information is available to assist you in product design and development. Check out the *Inertial Systems Primer* on our website, and be sure to register for access to a wide range of resources:

PRODUCT SPECIFICATIONS	TECHNICAL NOTES	APPLICATION NOTES
▪ User Manual	▪ Time Synchronization	▪ Gimbal Stabilization & Pointing
▪ Interface Control Document	▪ Hard & Soft Iron Calibration	▪ Satellite Communications
▪ Datasheet	▪ External GNSS Aiding	▪ Lidar Mapping
▪ Quick Start Guide	▪ Firmware Update	▪ Aerial Photogrammetry

All VectorNav products are backed by our customer-focused, robust and responsive support ecosystem. Our team is committed to supporting you through your entire product life-cycle, from concept design to in-field support. Please feel free to contact us by phone or email, our global team of engineers and representatives is ready to work with you through every challenge you know of, and every challenge you don't.

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1 INTRODUCTION

1.1 INDUSTRIAL SERIES OVERVIEW

The Industrial Series product line is built on a temperature-calibrated, high-performance, industrial-grade inertial measurement unit (IMU) and offers robust inertial navigation solutions for a wide range of applications and operating environments. Within the series are three distinct products: an IMU/AHRS (VN-100), a GNSS-aided inertial navigation system (GNSS/INS) (VN-200), and a Dual GNSS/INS (VN-300). The VN-100 is perfect for applications requiring calibrated IMU data or a real-time, drift-free attitude solution, particularly in systems that do not have GNSS visibility. The VN-200 combines its inertial sensor data with the onboard GNSS measurements to provide a full, robust navigation solution that is proven to excel in the most challenging dynamic conditions. The VN-300 is designed for applications that require a highly accurate inertial navigation solution under both static and dynamic operating conditions, particularly in environments with unreliable magnetic heading and good GNSS visibility. For help in determining which sensor is best for your particular application, please contact the VectorNav Sales or Support team.

1.2 PRODUCT DESCRIPTION

The VN-100 is a miniature, high-performance inertial measurement unit (IMU) and attitude and heading reference system (AHRS) offered in two distinct form factors —a surface-mount version designed to be directly embedded into a user's electronics and a more ”plug and play” version housed in an aluminum enclosure. Incorporating the latest solid-state MEMS sensor technology, the VN-100 combines a set of 3-axis accelerometers, 3-axis gyroscopes, 3-axis magnetometers, a barometric pressure sensor, and a 32-bit processor. The VN-100 is considered both an IMU in that it can output acceleration, angular rate, and magnetic measurements as well as an AHRS in that it can output filtered attitude estimates with respect to a local coordinate frame.

1.3 FACTORY CALIBRATION

MEMS inertial sensors are subject to several common sources of error: bias, scale factor, misalignment, temperature dependencies, and gyro g-sensitivity. All VN-100 sensors undergo a rigorous calibration process at the VectorNav factory to calculate the necessary coefficients to compensate for these error sources. Calibration parameters calculated during this process are permanently stored in flash memory on each individual sensor and digitally applied to the real-time measurements. The VN-100 is available with the following calibration options:

- Standard Calibration—this option provides a single temperature point calibration at 25 °C, which typically holds performance specifications when operating in an environment with a range of 15 °C to 35 °C.
- Thermal Calibration—this option extends the calibration process over multiple temperatures to ensure performance specifications are met over the full operating temperature range of −40 °C to +85 °C.

1.4 OPERATION OVERVIEW

The VN-100 has a built-in microcontroller that runs a quaternion-based extended Kalman filter (EKF), which provides estimates of both the attitude of the sensor and the real-time gyro biases. A quaternion-based attitude filter is used because it is continuous over a full 360° range of motion such that there are no limitations on the angles it can compute. However, the VN-100 also has a built-in capability to output yaw-pitch-roll angles, in which the sensor automatically converts from quaternion to the desired attitude parameter.

The VN-100 EKF combines measurements from the onboard inertial sensors and two reference vectors in estimating the attitude: gravity down and Magnetic North. Acceleration measurements from the 3-axis accelerometer are compared to the expected magnitude and direction of gravity to determine the pitch and roll angles. Measurements from the 3-axis magnetometer are compared to the local magnitude and direction of Earth's background magnetic field to determine the heading angle (i.e. yaw angle with respect to Magnetic North).

> ! The VN-100 EKF assumes that the accelerometer only measures the gravity reference vector. Applications that experience sustained dynamic accelerations can suffer degraded pitch and roll estimates. If real-time system velocity measurements are provided to the VN-100, the sustained dynamic acceleration can be estimated and compensated for using the velocity aiding feature (see TN005: Velocity Aiding for more information).

> ! The VN-100 EKF compares the onboard magnetic measurements to Earth's background magnetic field for the heading angle determination. Common objects such as batteries, electronics, cars, rebar in concrete, and other ferrous materials can bias and distort the background magnetic field, leading to more measurement errors. These errors can be identified and compensated for using a hard and soft iron (HSI) calibration (See Section 2.3.5 for more information).

> i VectorNav has developed a suite of tools called the Vector Processing Engine (VPE™), which are built in the VN-100 to minimize the effects of magnetic disturbances; however, it is not possible to obtain absolute heading accuracies better than 2° over any extended period of time when relying on magnetometer measurements.

The VN-100 EKF also integrates measurements from the 3-axis gyroscopes to provide faster and smoother attitude estimates as well as angular rate measurements. Gyroscopes of all kinds are subject to bias instabilities, in which the zero readings of the gyro will drift over time due to the inherent noise properties of the gyro itself. The VN-100 EKF uses the accelerometer and magnetometer measurements to continuously estimate the gyro bias, such that the reported angular rates are compensated for this drift.

1.5 MEASUREMENT OUTPUT OPTIONS

Outputs from the VN-100 include:

- Time
  - Time since sensor startup
  - Time relative to I/O synchronization events
- Attitude estimates
  - Yaw-Pitch-Roll (YPR)
  - Quaternion
  - Direction Cosine Matrix (DCM)
- Angular rate measurements
  - Raw (factory-calibrated) angular rate
  - Bias-compensated angular rate
- Acceleration measurements
  - Raw (factory-calibrated) acceleration
- Magnetic measurements
  - Raw (factory-calibrated) magnetic measurements
  - Real-time HSI-compensated magnetic measurements
- Barometric pressure
- Uncertainties
  - Yaw-Pitch-Roll

1.6 PACKAGING OPTIONS

The VN-100 is available in two different packaging options: a 30-pin surface-mount device (SMD) and an aluminum-encased rugged module. The VN-100 SMD is well suited for customers looking to integrate the sensor at the electronics level while the VN-100 Rugged provides a precision enclosure with mounting tabs and alignment holes for an off-the-shelf solution.

1.6.1 Surface-Mount Package

For embedded applications, the VN-100 is available in a miniature surface-mount device.

Features:

- Small size: 22 x 24 x 3 mm
- Low weight: 3.5 g
- Single power supply: 3.2 to 5.5 V
- Communication interface: Serial TTL and SPI
- Low power requirement: < 45 mA at 3.3 V

VN-100 SMD

FIGURE 1.1

1.6.2 Surface-Mount Development Kit

The VN-100 SMD Development Kit provides the VN-100 SMD sensor installed onto a small PCB, allowing for easy access to all the features and pins on the VN-100. Communication with the VN-100 is provided by USB and RS-232 serial communication ports. A 30-pin header provides easy access to each of the critical pins. The VN-100 SMD Development Kit also includes all the necessary cabling and documentation.

Features:

- Pre-integrated VN-100 sensor
- Board Size: 76 x 76 x 14 mm
- 30-pin 0.1 inch header to access the VN-100 pins
- Onboard USB to serial converter
- Onboard TTL to RS-232 converter
- Power supply connector - 5V (can be powered via USB)
- User Manual, Interface Control Document, & Quick Start Guide
- Carrying case

VN-100 SMD Development Kit

FIGURE 1.2

1.6.3 Rugged Package

The VN-100 Rugged consists of the VN-100 sensor installed and calibrated in a robust, precision aluminum enclosure.

Features:

- Precision aluminum enclosure
- Compact size: 36 x 33 x 9 mm
- Low weight: 16 g
- Locking 10-pin Harwin connector
- Mounting tabs with alignment holes
- Single power supply: 4.5 to 5.5 V
- Communication interface: Serial RS-232 and TTL
- Low power requirement: < 40 mA at 5 V

VN-100 Rugged

FIGURE 1.3

1.6.4 VN-100 Rugged Development Kit

The VN-100 Rugged Development Kit includes the VN-100 Rugged sensor along with all the necessary cabling required for operation. Two cables are provided in each Development Kit: one for RS-232 communication and a second custom cable with a built-in USB converter. The Development Kit also includes all the relevant documentation.

Features:

- VN-100 Rugged sensor
- 10 ft RS-232 cable
- 10 ft USB connector cable
- Cable connection tool
- User Manual, Interface Control Document, & Quick Start Guide
- Carrying case

VN-100 Rugged Development Kit

FIGURE 1.4

1.7 REFERENCE FRAMES

The VN-100 provides its output data in either the sensor-frame or body-frame, which are coincident by default. The VN-100 uses a right-handed reference frame.

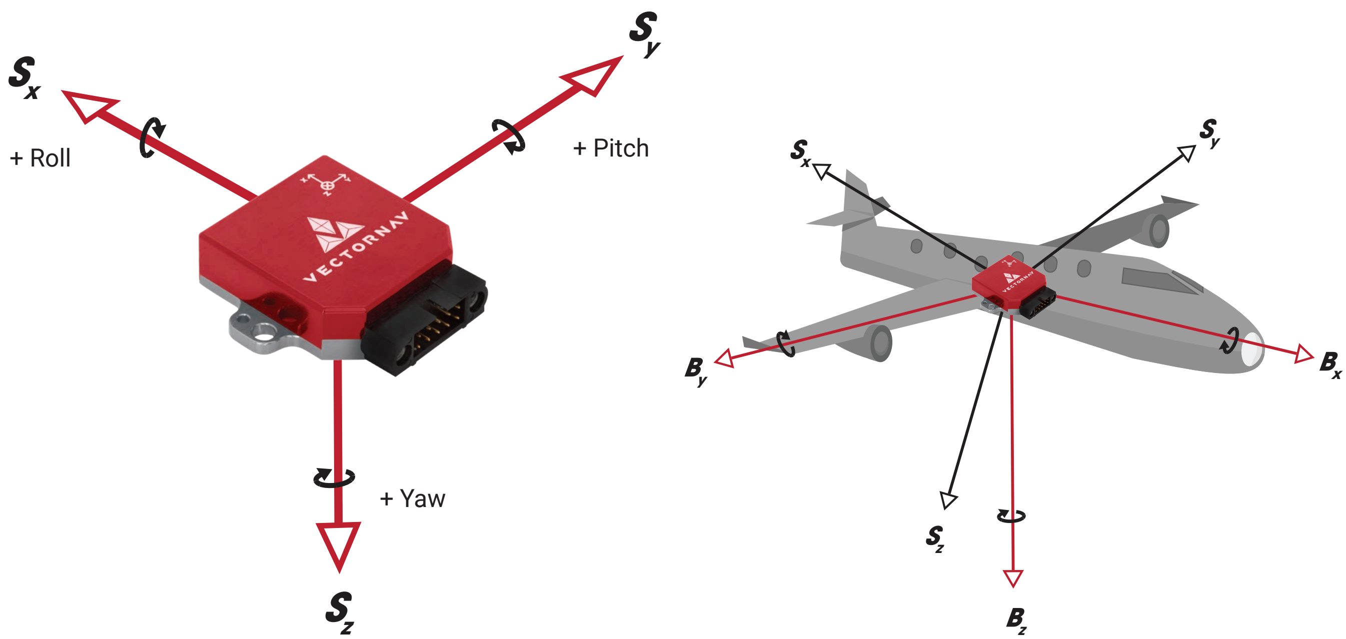
1.7.1 Sensor-Frame

The sensor-frame on the VN-100 is aligned as shown in Figure 1.5a. The x-axis points forward, the y-axis points rightward, and the z-axis points downward. A positive yaw angle is defined as a positive right-handed rotation around the z-axis; a positive pitch angle is defined as a positive right-handed rotation around the y-axis; a positive roll angle is defined as a positive right-handed rotation around the x-axis. The sensor-frame is shown on the top of the sensor's casing.

1.7.2 Body-Frame

In many cases, the user may want to read the VN-100 output values in an arbitrary reference frame (body-frame), whether due to mechanical offsets, a mounting misalignment, or system-level integration. The new reference frame is often the mounting platform, vehicle, aircraft, camera, LiDAR sensor, external INS, or any other body rigidly attached to the sensor. The new frame may be rotated any amount relative to the sensor-frame using a reference frame rotation (RFR) which can be applied via the Reference Frame Rotation register (Register 26). Figure 1.5b shows an example of such a case where an RFR is needed to rotate the sensor-frame to the body-frame.

Reference Frames



(a) Sensor-Frame

(b) Example Requiring an RFR

FIGURE 1.5

2 INITIAL SETUP

The VN-100 has been designed to require minimal configuration by the end user for normal operation. This section provides a high-level overview of the recommended steps that the end user should follow to ensure proper operation of the VN-100 in the intended application.

2.1 DEFAULT BEHAVIOR

Unless otherwise noted, the following holds true:

- Changes to register settings take effect immediately
- Default baud rate (UART-1): 115200
- Default baud rate (UART-2): 115200
- Default ASCII output message (UART-1): VNYMR at 40 Hz
- Default ASCII output message (UART-2): VNYMR at 40 Hz
- Default user low-pass filtering window size of 4 for accelerometer, gyroscope, and temperature data
- Default user low-pass filtering window size of 0 for magnetometer and pressure data
- Default VPE heading mode: Relative Mode

2.2 VN-100 MOUNTING RECOMMENDATIONS

When mounting the VN-100 onto an aircraft, vehicle, or other platform, careful consideration must be made to ensure optimal performance from the sensor. In order to provide an attitude solution for a particular platform, the VN-100 needs to be able to directly measure the motion of that platform. To do so, the VN-100 must be **rigidly mounted** to the platform. The surface mount version (SMD) of the VN-100 requires the sensor to be **hand soldered** when installed onto its carrier board. More information on the installation of the VN-100 SMD can be found in the VN-100 SMD Datasheet. Additionally, any cabling used to connect to the sensor, or its carrier board in the case of the SMD, should be properly **strain-relieved** to prevent stress on the sensor. Failure to rigidly secure the sensor to the desired platform can introduce erroneous IMU measurements that will negatively impact the performance of the sensor. The use of vibration dampeners or flexible mounts prevents the VN-100 from directly measuring the motion of the platform and are generally not recommended.

There are no assumptions made as to the installation alignment of the VN-100, thus the sensor can be mounted to the platform in **any orientation** and at **any location**. Once mounted, if the sensor-frame does not align with the desired body-frame, then a Reference Frame Rotation (RFR) will be required to map the sensor-frame to the body-frame. More information on this register can be found in Section 2.3.2.

> **Do not reflow** the VN-100. The SMD version of the VN-100 must be **hand soldered**.

2.3 VN-100 BASIC CONFIGURATION

During the initial setup of the VN-100, there are no configuration settings required for operation, though the user may wish to modify various register settings such as the baud rate or output messages. The following sections describe the most commonly modified settings on the VN-100—for the full list of configuration registers available, refer to the VN-100 Interface Control Document.

2.3.1 Saving User-Configured Settings

The user's desired settings are configured onto the VN-100 using the corresponding Write Register command. However, the Write Register command only saves the settings to the volatile memory of the sensor which will cause the configuration to be erased after a power cycle or reset of the device. To save the user-configured settings to the sensor's non-volatile memory, allowing them to persist through a power cycle or reset, a Write Settings command must be sent to the sensor after the desired Write Register commands have been applied. More information on the Write Settings command can be found in the VN-100 Interface Control Document.

2.3.2 Applying a Reference Frame Rotation

Under default settings, the VN-100 assumes that its sensor-frame (Section 1.7.1) is coincident with the desired body-frame (Section 1.7.2) of the platform to which it is rigidly mounted. However, this is not a mounting requirement and many applications may desire the sensor output values in an arbitrary reference frame instead, whether due to mechanical offsets, a mounting misalignment, or system-level integration. Common examples of such cases include a mounting platform frame (i.e. vehicle, aircraft, etc.) or an external sensor-frame (i.e. camera, LiDAR, etc.) that differs from the VectorNav sensor-frame.

A reference frame rotation (RFR) can be applied to the sensor via the Reference Frame Rotation register (Register 26) to rotate the sensor outputs to the desired body-frame. Because the RFR gets applied at a low level and affects all measurements that are used in the filter, these settings must be saved to the non-volatile memory of the sensor through a Write Settings command and then the sensor must be reset or power cycled before the RFR takes effect. For a more detailed analysis and discussion of how to calculate a reference frame rotation, refer to TN004: Reference Frame Rotation.

2.3.3 Configuring the Desired Baud Rate

The VN-100 provides the ability to modify the baud rate of each serial port independently through the Baud Rate register (Register 5). The baud rate can be configured at specified rates from 9600 bps up to a maximum of 921600 bps. This allows the user to customize how fast the data is transmitted across the serial line for their specific system requirements.

2.3.4 Configuring the Desired Output Messages

The VN-100 provides two different means of obtaining measurements—using either human-readable ASCII messages or user-configurable custom binary output messages.

Human-Readable ASCII Messages

The VN-100 provides a variety of proprietary measurement output combinations which can be selected using the Async Data Output Type register (Register 6). The rate of the output can be adjusted from 1 to 200 messages per second using the Async Data Output Freq register (Register 7). Each different proprietary ASCII output message type has its own unique five-character header string so that it can easily be distinguished in the data stream.

User-Configurable Binary Output Messages

Alternatively, for higher rate data or custom message outputs, the VN-100 also supports the ability to construct user-defined binary output messages through the Binary Output Message Configuration registers (Registers 75-77). This option allows the user to select a subset of the available measurements that the VN-100 offers and have it packaged into a single compact binary packet provided at any rate up to the IMU Rate of the sensor. Up to three different custom messages can be created, each with its own separate output rate, and configured to output over one or both of the serial ports.

2.3.5 Hard and Soft Iron Calibration

A hard and soft iron (HSI) calibration should be performed on the VN-100 in applications in which an accurate heading solution is needed. The VN-100 uses its onboard magnetometer to estimate the heading of the sensor with respect to Magnetic North. Using a magnetometer to accurately estimate the heading can prove to be quite challenging as Earth's magnetic field is relatively weak and there often exist magnetic fields created by objects near the VN-100, known as magnetic disturbances. These magnetic disturbances bias and distort Earth's background magnetic field leading to errors in the estimated heading. An HSI calibration can be used to account for any time-invariant magnetic disturbances that are rigidly attached to the VN-100. More information on performing an HSI calibration on the VN-100 can be found in TN002: Hard & Soft Iron (HSI) Calibration.

> To reference the heading to True North rather than Magnetic North, the declination angle can be applied through either the Magnetic and Gravity Reference Vectors register (Register 21) or the Reference Model Configuration register (Register 83) as discussed in Section 2.3.9.

2.3.6 Configuring the VPE Heading Mode

As part of its collection of algorithms, the Vector Processing Engine (VPE) includes three distinct heading modes known as Absolute Mode, Relative Mode, and Indoor Mode. These heading modes control how the magnetic measurements are interpreted in the magnetic-based heading estimation and were designed as a way to handle any external magnetic disturbances the sensor may encounter in its environment. More details on how each heading mode handles magnetic disturbances as well as the recommended use case for each mode can be found in Section 3.3.5. The desired heading mode can be configured on the VN-100 using the *HeadingMode* field in the VPE Basic Control register (Register 35).

> The heading modes are not intended to account for any internal magnetic disturbances, which are characterized as magnetic disturbances that are rigidly mounted to the VN-100. To account for any internal magnetic disturbances, an HSI calibration should be performed on the VN-100 as discussed in Section 2.3.5.

2.3.7 Configuring the VPE Adaptive Tuning & Filtering

The Vector Processing Engine (VPE) provides the ability to adaptively tune and filter the accelerometer and magnetometer measurements prior to entering the onboard Kalman filters allowing for improved performance in the presence of vibration, short-term accelerations, and some forms of magnetic disturbances. The amount of tuning and filtering applied to these measurements can be adjusted in the VPE Magnetometer Basic Tuning register (Register 36) and the VPE Accelerometer Basic Tuning register (Register 38). The *BaseTuning* fields within these registers control how much trust the filter will place in the magnetometer and accelerometer readings when estimating the attitude. The *AdaptiveTuning* and *AdaptiveFiltering* fields adjust the amount of adaptive tuning and adaptive filtering employed by the VPE algorithms. More information on these adaptive tuning and filtering settings can be found in Section 3.3.4.

> In a majority of applications, the VN-100 can be used with the default tuning and filtering values for best performance. If desired, the *BaseTuning* fields can be adjusted by the user to control how much trust is placed in the magnetometer and accelerometer, though generally modifying the *AdaptiveTuning* and *AdaptiveFiltering* fields is not recommended.

2.3.8 Configuring the User Low-Pass Filter

The VN-100 provides the ability to apply a user-defined, moving window low-pass filter to the output IMU measurements through the IMU Filtering Configuration register (Register 85). This low-pass filter can be used to downsample the inertial sensor data (i.e. acceleration, angular rate, magnetic data, temperature, and pressure) and prevent aliasing when these measurements are output at rates lower than the IMU Rate. The *WindowSize* fields in this register allow the user to adjust the number of samples that are averaged for each output inertial sensor measurement while the *FilterMode* fields select which output quantities to apply the filtering to — uncompensated data, compensated data, or both. When configuring the desired window size, keep in mind that this filtering will also introduce increased latencies in the response of the output sensor measurements and decreased bandwidth available. More information on the IMU Filtering Configuration register can be found in the VN-100 Interface Control Document.

> This low-pass filter is only applied to the measurements output to the user and does not affect the data used in the onboard filter.

2.3.9 Applying the Declination Angle

By default, the VN-100 references its magnetic-based heading to Magnetic North . To instead reference the magnetic-based heading to True North , the declination angle (δ) can be applied through either the Magnetic and Gravity Reference Vectors register (Register 21) or the Reference Model Configuration register (Register 83).

The Magnetic and Gravity Reference Vectors register (Register 21) allows the user to manually apply the magnetic reference vector onto the sensor. By default, this register is set to a 0° declination angle, meaning the yaw angle will be referenced to Magnetic North. The local magnetic reference vector can be obtained directly from the World Magnetic Model or calculated from the declination angle using the following:

$$MagRefX = cos(\delta) \quad (2.1)$$

$$MagRefY = sin(\delta) \quad (2.2)$$

These parameters should then be configured into the corresponding fields in Register 21. Once configured, the onboard filter will use this local magnetic reference vector to account for the declination angle in the magnetic-based heading.

The Reference Model Configuration register (Register 83) can alternatively be used to apply the declination angle by enabling the onboard World Magnetic Model (WMM). To utilize the WMM, the *EnableMagModel* field should be set to 1 and the current location of the sensor and decimal year must be input into the *Year*, *Latitude*, *Longitude*, and *Altitude* fields. Once configured, this register will apply the local magnetic reference vector and declination angle, improving the accuracy of the heading. If the WMM is disabled by setting the *EnableMagModel* to 0, the user-configured reference vector in the Magnetic and Gravity Reference Vectors register (Register 21) will be used instead.

> The WMM onboard the VN-100 can be updated every five years similarly to a firmware update. To obtain the latest WMM for your sensor, please reach out to the VectorNav Support team.

3 SOFTWARE ARCHITECTURE

The VN-100 software architecture consists of four subsystems: IMU, NavState, Vector Processing Engine (VPE), and Communication Interface. The high-level functions performed by these subsystems are outlined in Figure 3.1. This section describes the functions performed by, and outputs of, each of these subsystems.

3.1 IMU SUBSYSTEM

The IMU subsystem runs at the highest system rate (default 800 Hz), referred to as the IMU Rate. It is primarily responsible for handling the raw IMU measurements and maintaining consistent system timing. After sampling the IMU components, this subsystem applies a factory calibration, a user-defined calibration, and a user-defined reference frame rotation. The resultant calibrated, body-frame IMU measurements are then passed to the NavState subsystem to be used for propagation. The IMU subsystem produces three different types of outputs: uncompensated outputs, compensated outputs that have the real-time bias compensation values applied, and delta outputs from the coning and sculling integration. The IMU subsystem is responsible for timestamping the IMU measurements to internal system time and relative to the SyncIn signal. These processes are described in more detail in this section.

FACTORY CALIBRATED	BIAS COMPENSATED	INTEGRALS
▪ Acceleration	▪ Angular Rate	▪ Delta Theta
▪ Angular Rate	▪ Magnetic	▪ Delta Velocity
▪ Magnetic		▪ Delta Time

3.1.1 Raw IMU Measurement

The raw IMU measurement stage consists of two parts: the IMU sampling and the factory calibration. First, the internal MEMS are sampled at the highest rate available for each individual sensor, downsampling the gyroscope and accelerometer to the IMU Rate. Second, the factory calibration parameters discussed in Section 1.3 are applied to each sample. These factory calibration parameters are permanently stored on the sensor, and cannot be altered or removed. Once the factory calibration parameters are applied to an IMU sample, it is referred to as a raw IMU measurement.

3.1.2 User Calibration

The user calibration stage provides the user with the ability to apply an additional user-defined IMU calibration to remove additional bias, scale factor, and axis misalignment errors. The user calibration is most often used to account for errors that are induced through the lifespan of the part but is optional and, in most cases, not required for normal operation. The magnetometer, accelerometer, and gyroscope calibration parameters can be configured in Register 23, Register 25, and Register 84, respectively.

3.1.3 User Reference Frame Rotation

The user reference frame rotation stage provides the user with the ability to redefine the body-frame (discussed in Section 1.7.2) by a rigid-body rotation, which consequently rotates each of the IMU outputs. Because body-frame IMU measurements are used in the attitude estimation algorithms this setting will impact all body-frame outputs including all attitude estimation calculations. The reference frames used by the sensor are discussed in Section 1.7 and can be configured in Register 26. The output of this stage is referred to as a body-frame IMU measurement.

3.1.4 Measurement Compensation

The measurement compensation stage compensates each IMU measurement by the real-time calculated bias. Using the VPE state outputs, it subtracts the real-time gyroscope biases and, if enabled, the real-time HSI magnetic

VN-100 Software Architecture

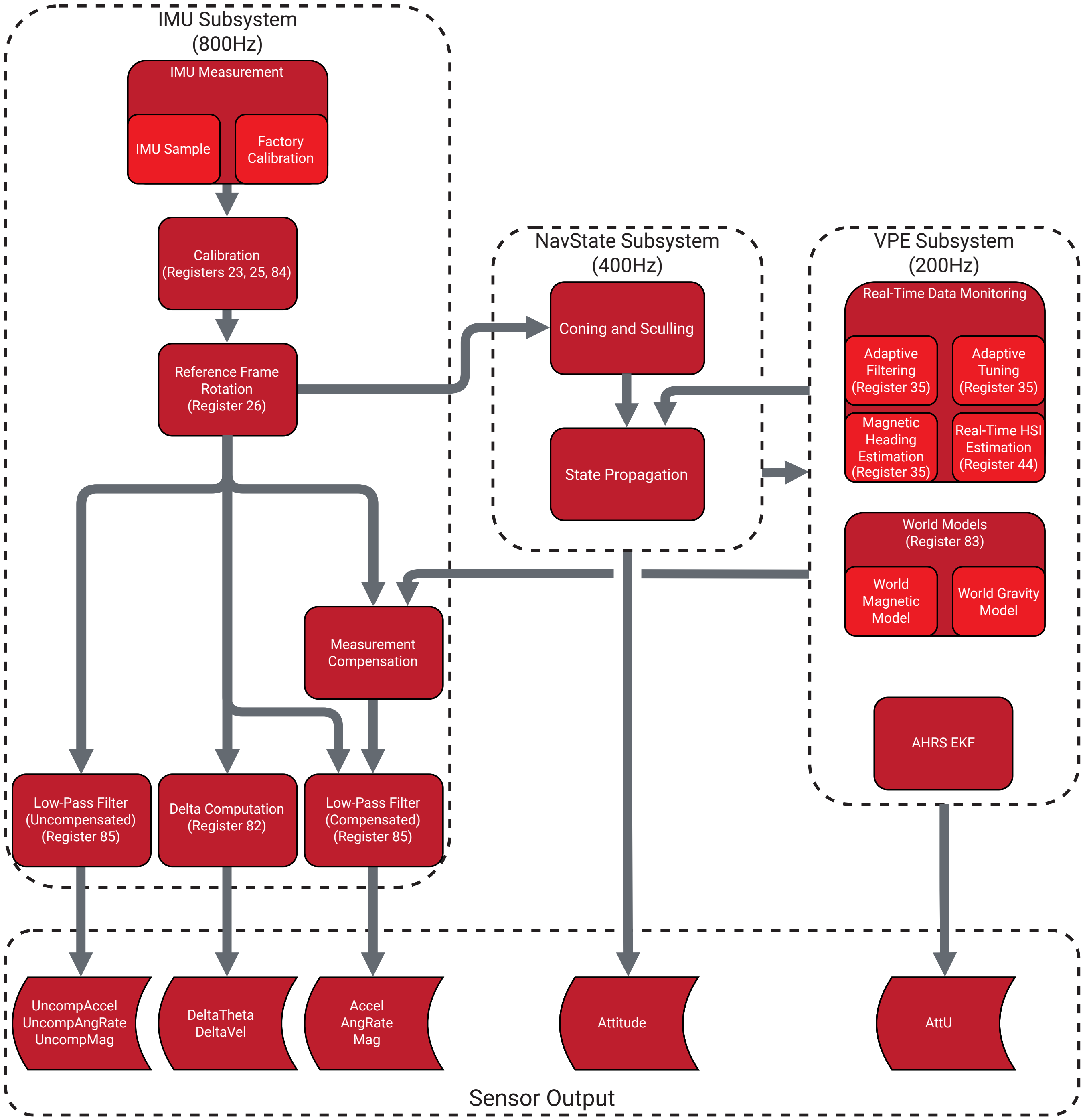


FIGURE 3.1

disturbances from the body-frame IMU measurements. Because the real-time acceleration biases are not calculated by the VPE, they are not compensated by the measurement compensation stage.

3.1.5 User Low-Pass Filter

The user low-pass filter stage allows the user with the ability to apply a user-defined, low-pass filter to the output IMU measurements. This can be used to downsample the output IMU measurements to ensure that information is not lost when the IMU measurements are output at a rate lower than the IMU Rate. The low-pass filter can be configured independently for each of the uncompensated and compensated magnetometer, accelerometer, and gyroscope measurements through the IMU Filtering Configuration register (Register 85). This filtering only impacts the IMU measurement outputs; no onboard estimation algorithms will be affected by this setting. Because the measurement compensation stage does not calculate compensated acceleration measurements, the low-pass filter (compensated) stage uses the uncompensated acceleration measurements, and the output acceleration measurements are consequently not compensated for real-time bias. The outputs of this stage are directly available to the user.

3.1.6 Delta Computation

The delta computation stage is responsible for calculating and outputting the delta theta, delta velocity, and delta time outputs. These outputs represent the change in 3-axis angle, 3-axis velocity, and time between the current delta output and prior delta output. To calculate the delta values, the IMU subsystem computes and accumulates the coning and sculling integrals, resetting them each time the deltas are output—whether by ASCII message, binary message, or polling the Delta Theta and Delta Velocity register (Register 80) directly. Regardless of the delta output rate, the coning and sculling integrals are performed at the IMU Rate. Based on the selected configuration, the delta computation stage can optionally utilize gravity- or bias-compensated IMU measurements or output in the NED reference frame. For this functionality, this stage will receive data from, and be dependent upon, the NavState and VPE subsystems. The outputs of this stage are directly available to the user.

3.1.7 Timestamping

All onboard IMU measurements are timestamped relative to two internal timing events: the monotonically increasing system time (*TimeStartup*) and the time since the last SyncIn Event (*TimeSyncIn*). These timestamps are recorded with nanosecond resolution and approximately 20 µs accuracy relative to the onboard temperature-compensated crystal oscillator. The onboard oscillator has a timing accuracy of approximately 20 ppm over the sensor's operating temperature range. More information on the timing events and processing steps of the VN-100 can be found in TN001: Time Synchronization.

3.2 NAVSTATE SUBSYSTEM

The NavState subsystem runs at a rate fixed to the IMU Rate, referred to as the NavState Rate (default 400 Hz). It is primarily responsible for generating a continuous, reliable stream of low-latency, low-jitter state outputs at a rate higher than the VPE Rate. To accomplish this, the NavState propagates forward the latest VPE states using the IMU measurements, decoupling the rate at which the state outputs are estimated by the onboard Kalman filters from the rate at which they are made available to the user. This process not only effectively upsamples the VPE state outputs, but also guarantees the VN-100 state output timing is unaffected by system load and input measurement availability. Consequently, the NavState is important for many applications which depend on low-latency, low-jitter estimates as inputs to their control loops. The NavState subsystem runs immediately after, and in sync with, the IMU subsystem.

ATTITUDE
- Yaw-Pitch-Roll
- Quaternion
- Direction Cosine Matrix (DCM)

3.3 VPE SUBSYSTEM

The Vector Processing Engine (VPE) subsystem runs at the VPE Rate (default nominally 200 Hz) and is primarily responsible for calculating the fused inertial state outputs through the AHRS Kalman filter. Because the VPE is dependent upon measurement availability and runs at a relatively low rate, some VPE states are passed to the NavState subsystem to be output at a higher rate. Others are output to the user directly from the VPE subsystem and as such are only updated at the VPE Rate.

In addition to the Kalman filter, the VPE subsystem also includes a collection of sophisticated algorithms which provides real-time monitoring and simultaneous estimation of the attitude as well as the uncertainty of the input measurements used by the attitude estimation algorithm. By estimating its own input measurement uncertainty the VPE is capable of providing significantly improved performance when compared to traditional statically tuned Kalman filters. The estimated measurement uncertainty is used to, in real-time, adaptively tune the onboard Kalman filters. In most cases this adaptive tuning eliminates the need for the user to perform any custom filter tuning for different applications. It also provides robust disturbance rejection capabilities, enabling the VN-100 in most cases to reliably estimate attitude even in the presence of vibration, short-term accelerations, and some forms of magnetic disturbances.

UNCERTAINTIES	INERTIAL BIASES
▪ Attitude	▪ Gyroscope

3.3.1 AHRS Kalman Filter

The AHRS Kalman filter is an extended Kalman filter (EKF) that estimates the full quaternion-based attitude as well as the time-varying gyroscope bias. Because the EKF is quaternion-based (as opposed to Euler-angle–based), it contains no geometric singularities, thus eliminating any potential gimbal lock issues otherwise incurred at high pitch angles. The real-time estimation of the gyroscope bias allows for the removal of small perturbations in the gyroscope bias which occur over time due to random walk.

3.3.2 Adaptive Filtering

The VPE employs adaptive filtering techniques to significantly reduce the effect of high-frequency magnetic and acceleration disturbances. Prior to entering the AHRS filter, the magnetic and acceleration measurements are digitally filtered to reduce high-frequency components typically caused by electromagnetic interference and vibration. The level of filtering applied to the inputs is dynamically altered by the VPE in real time. The VPE calculates the minimal amount of digital filtering required in order to achieve specified orientation accuracy and stability requirements. By applying only the minimal amount of filtering necessary, the VPE reduces the amount of delay added to the input signals. For applications that have very strict latency requirements, the VPE provides the ability to limit the amount of adaptive filtering performed on each of the input signals or to disable it entirely.

3.3.3 Adaptive Tuning

Kalman filters employ coefficients that specify the uncertainty in the input measurements which are typically used as tuning parameters to adjust the behavior of the filter. Normally these tuning parameters have to be adjusted by the engineer to provide adequate performance for a given application. This tuning process can be ad-hoc, time-consuming, and application-dependent. The VPE employs adaptive tuning logic which provides online estimation of the uncertainty of each of the input signals during operation. This uncertainty is then applied directly to the onboard AHRS filter to correctly account for the uncertainty of the inputs. The adaptive tuning reduces the need for manual filter tuning.

3.3.4 Adaptive Filtering and Tuning Settings

The VPE actively employs both adaptive filtering and adaptive tuning techniques to enhance performance in conditions of dynamic motion and magnetic and acceleration disturbances. The VPE provides the ability to modify the amount of adaptive filtering and tuning applied on both the magnetometer and the accelerometer through the VPE Magnetometer Basic Tuning register (Register 36) and the VPE Accelerometer Basic Tuning register (Register 38). In most cases the VPE can be used in the default configuration without any need to adjust these settings. For some applications, higher performance can be obtained by adjusting the amount of adaptive filtering and tuning performed on the inputs. The following settings are provided for both the magnetometer and accelerometer.

Static Measurement Uncertainty

The static gain adjusts the level of uncertainty associated with either the magnetic or acceleration measurement when no disturbances are present. The level of uncertainty associated with the measurement will directly influence the accuracy of the estimated attitude solution. The level of uncertainty in the measurement will also determine how quickly the attitude filter will correct for errors in the attitude when they are observed. The lower the uncertainty, the quicker it will correct for observed errors.

- This parameter can be adjusted from 0 to 10.
- Zero places no confidence (or infinite uncertainty) in the sensor, thus eliminating its effect on the attitude solution.

- Ten places full confidence (minimal uncertainty) in the sensor and assumes that its measurements are always 100% correct.

Adaptive Tuning Gain

The adaptive tuning stage of the VPE monitors both the magnetic and acceleration measurements over an extended period of time to estimate the time-varying level of uncertainty in the measurement. The adaptive tuning gain directly scales either up or down this calculated uncertainty.

- This parameter can be adjusted from 0 to 10.
- The minimum value of zero turns off all adaptive tuning.
- The maximum value of 10 applies several times the estimated level of uncertainty.

Adaptive Filtering Gain

The adaptive filtering stage of the VPE monitors both the magnetic and acceleration measurements to determine if large-amplitude, high-frequency disturbances are present. If so, then a variable level of filtering is applied to the inputs in order to reduce the amplitude of the disturbance down to acceptable levels prior to inputting the measurement into the attitude filter. The advantage of adaptive filtering is that it can improve accuracy and eliminate jitter in the output attitude when large-amplitude AC disturbances are present. The disadvantage to filtering is that it will inherently add some delay to the input measurement. The adaptive filtering gain adjusts the maximum allowed AC disturbance amplitude for the measurement prior to entering the attitude filter. The larger the allowed disturbance, the less filtering that will be applied. The smaller the allowed disturbance, the more filtering will be applied.

- This parameter can be adjusted from 0 to 10.
- The minimum value of zero turns off all adaptive filtering.
- The maximum value of 10 applies maximum filtering.

Keep in mind that regardless of this setting, the adaptive filtering stage will apply only the minimal amount of filtering necessary. As such, this parameter provides the ability to set the maximum amount of delay that is acceptable in the input measurement.

3.3.5 Heading Modes

As part of its collection of algorithms, the VPE includes three independent heading modes: Absolute Mode, Relative Mode, and Indoor Mode. These heading modes control how the VPE interprets the magnetic measurements in estimating magnetic-based heading and are described in detail in the following sections. The particular heading mode of the VN-100 can be configured using the *HeadingMode* field in the VPE Basic Control register (Register 35).

While each mode is unique in how it handles magnetic measurements, all three modes are capable of handling high-frequency external magnetic disturbances greater than 1 Hz as well as constant external magnetic disturbances lasting less than a few seconds. The distinction between the various modes becomes crucial for external magnetic disturbances lasting longer than a few seconds.

The different heading modes were designed as a way to handle external magnetic disturbances the VN-100 may encounter in its environment and are not intended to account for any internal magnetic disturbances which are rigidly mounted with respect to the sensor. A hard and soft iron (HSI) calibration should be performed on the sensor to handle any internal magnetic disturbances. If a valid HSI calibration is not performed prior to use, the behavior of these heading modes can be impacted and may not operate as expected. More information on performing an HSI calibration can be found in TN002: Hard & Soft Iron (HSI) Calibration.

Absolute Mode

In Absolute Mode, the VPE assumes the magnetometer is measuring Earth's magnetic field alone and no external magnetic disturbances are present. As such, only short-term magnetic disturbances greater than 1 Hz are tuned out. Unfortunately, long-term external magnetic disturbances cannot be handled in Absolute Mode as a constant long-term external magnetic disturbance will be indistinguishable from Earth's magnetic field and will, consequently, result in a loss of heading accuracy.

Because of the assumptions placed on the magnetometer measurements, Absolute Mode can also impact the estimation of the real-time gyroscope bias in addition to the heading estimate. When a long-term external magnetic disturbance is encountered, the magnetometer will measure more than just Earth's magnetic field, causing the magnetic-based yaw to slew over to an erroneous heading estimate. Because this transition in the heading is not due a physical rotation of the sensor, a disagreement between the magnetometer and gyroscope measurements will arise. In order to resolve this mismatch between the two sensors, the real-time gyroscope bias estimate must be updated, often resulting in degradation of this estimate.

Absolute Mode is ideal for applications that do not encounter any external magnetic disturbances lasting more than a few seconds, such as an aircraft in flight or a marine vessel in open water. Additionally, this heading mode maintains absolute tracking of the heading relative to the fixed Earth, making it perfect for applications requiring a stable and repeatable heading. However, it is important to note that in order to track an absolute heading, any internal magnetic distortions need to be well characterized by performing a hard and soft iron (HSI) calibration on the VN-100. Hard and soft iron distortions that are not properly accounted for will induce heading errors proportional to the magnitude of the distortion.

> If a magnetic disturbance occurs due to an event controlled by the user, such as the switching on/off of an electric motor, an absolute heading can still be maintained if the VN-100 is notified of the presence of the disturbance using the Known Magnetic Disturbance command.

Relative Mode

In Relative Mode, the VPE places no assumptions on the magnetometer measurements and instead recognizes that the magnetometer is likely impacted by external magnetic disturbances in the surrounding environment in addition to measuring Earth's magnetic field. To minimize the impact of external magnetic disturbances on the derived heading, Relative Mode estimates the external magnetic field in real time using a comparison between the magnetometer and gyroscope measurements. This estimation process allows Relative Mode to ignore magnetic disturbances in the heading calculation when they are encountered in the environment.

While the heading estimate in Relative Mode will often remain stable in the presence of external magnetic disturbances, the estimation process used to track the external magnetic field is not perfect. The magnetic measurements themselves are often noisy and the integration of the angular rate measurements will drift over time due to the inherent noise and bias properties of the gyroscope. As a result, drift can accumulate in the heading solution, such that Relative Mode can only provide a relative heading and cannot always ensure the magnetic-based heading is referenced to Magnetic North. The amount of drift accrued depends on how many magnetic disturbances are encountered, how often they are encountered, and the magnetic strength of each disturbance. Additionally, if an HSI calibration has not been performed on the VN-100 to account for internal, time-invariant magnetic disturbances, drift will accumulate fairly rapidly as the sensor will continually encounter these disturbances.

Relative Mode is designed for use in situations where maintaining a stable attitude solution is the most important requirement. In general, Relative Mode will provide the most accurate heading of the three heading modes, particularly over the short term, even with some drift in the estimation process. Because Relative Mode provides a stable heading, it is also able to produce an accurate estimate of the gyroscope bias.

Indoor Mode

In any environment, the measured magnetic field is generally a blend of Earth's magnetic field and other local magnetic fields created by objects near the VN-100. For indoor environments in particular, this becomes problematic due to the potential proximity to objects such as metal desks and chairs, speakers, rebar in the concrete floor, and other items which either distort or produce their own magnetic field. The strength of these local magnetic fields is position-dependent; if the strength is on the same order of magnitude as that of Earth's magnetic field, directly trusting the magnetic measurements to determine heading can lead to inaccurate heading estimates.

Indoor Mode is ideal for applications in which the external magnetic disturbances are constantly changing and works best in cases where disturbances are short-lived and zero-mean, such as a sensor that is constantly in motion. When used in Indoor Mode, the VN-100 should be in proximity to magnetic disturbances for no more than a few seconds at a time. Unfortunately, a majority of applications will not experience such an environment and Indoor Mode may provide worse magnetic disturbance rejection than Relative Mode or Absolute Mode.

3.3.6 Real-Time Hard and Soft Iron Estimator

The VPE subsystem also includes a separate EKF which provides real-time estimation of the local magnetic hard and soft iron (HSI) distortions. Local HSI distortions are magnetic fields generated by electrical currents or ferrous materials which are constant relative to the position and orientation of the sensor. These distort the direction and magnitude of the measurement of Earth's magnetic field, thus negatively impacting the ability of the filter to reliably and accurately estimate its magnetometer-based heading. To remove the unwanted effect of these disturbances, an HSI calibration must be performed. This requires rotating the sensor around in multiple circles while collecting magnetic data for offline calculation of the magnetic hard and soft iron calibration coefficients. This calibration can be time-consuming and may not be possible for some applications. The Real-Time Hard and Soft Iron Estimator runs on the VN-100 in the background without requiring any user intervention. For many applications this simplifies the process for the end user and allows for operation in environments where HSI disturbances may change slowly over time. On the VN-100, the Real-Time Hard and Soft Iron Estimator is turned off by default, but can be enabled and configured by the Real-Time HSI Control register (Register 44). More information on the Real-Time Hard and Soft Iron Estimator can be found in TN002: Hard & Soft Iron (HSI) Calibration.

3.3.7 World Magnetic Model

The World Magnetic Model (WMM) is a large spatial-scale representation of Earth's magnetic field. The model used in the VN-100 consists of a spherical-harmonic expansion of the magnetic potential of the geomagnetic field generated in Earth's core. By default, the World Magnetic Model on the VN-100 is disabled allowing the user to directly set the reference magnetic field strength. The World Magnetic Model can be enabled and used to calculate the magnetic field strength for a given latitude, longitude, altitude, and date to be subsequently used as the fixed magnetic field reference strength. The Reference Model Configuration register (Register 83) can be used to control the World Magnetic Model.

3.3.8 World Gravity Model

The World Gravity Model (WGM) is a large spatial-scale representation of Earth's gravitational potential as a function of position on Earth. The internal model used on the VN-100 is consistent with the Earth Gravity Model (EGM96), which consists of a spherical-harmonic expansion of Earth's geopotential. By default, the World Gravity Model on the VN-100 is turned off allowing the user to directly set the reference gravity vector. As with the World Magnetic Model, the World Gravity Model can be enabled and used to calculate the gravitational potential for a given latitude, longitude, and altitude to be subsequently used as the fixed reference gravitational potential. The Reference Model Configuration register (Register 83) can be used to control the World Gravity Model.

3.4 COMMUNICATION INTERFACE

The VN-100 provides two distinct communication interfaces consisting of two independent serial ports and one serial peripheral interface (SPI) bus.

3.4.1 Serial (UART) Interface

The serial interface consists of two physically independent bidirectional UART serial ports. Each UART supports baud rates from 9600 bps up to a maximum of 921600 bps. The surface mount version (SMD) of the VN-100 offers both UARTs with 3V TTL voltage level inputs and outputs. The rugged version includes an onboard TTL to RS-232 level shifter, thus at the 10-pin connector one serial port is offered with RS-232 voltages levels (UART-1), while the other serial port (UART-2) remains at 3V TTL logic levels. More information on the VN-100 serial interface can be found in the VN-100 Interface Control Document.

> The ability to update the firmware using the onboard bootloader is only supported on the primary serial port (UART-1). It is highly recommended that if the primary serial port is not used for normal operation, a means of accessing it is designed into the product to support future firmware updates.

3.4.2 Serial Peripheral Interface (SPI)

A serial peripheral interface (SPI) bus is supported on the VN-100 SMD, which can be used to send data between multiple devices through a master and slave configuration. The VN-100 SMD operates as a slave on the SPI bus that can be enabled by a master device. The master device provides a clock signal to the slave to synchronize the data transfer between devices allowing for high data transfer rates. This communication interface is ideal for board-level communication over short distances. More information on the VN-100 SMD SPI communication interface can be found in the VN-100 Interface Control Document.

4 OPERATION

Understanding the operation of the VN-100 is critical to ensuring the sensor is integrated successfully and operating nominally. The following sections detail the recommended outputs to use in monitoring the status of the sensor and provide guidance for using the sensor in the most challenging conditions.

4.1 SENSOR STATUS

During operation of the VN-100, it is important to monitor the status of the sensor to ensure the quality of the overall solution. The following outputs provide an indication of the overall health of many of the different subsystems on the sensor and should be the first place to check if any problems arise when using the VN-100.

4.1.1 IMU Status Output

The *ImuStatus* output is a bitfield output that provides real-time monitoring of the onboard sensors (gyroscope, accelerometer, magnetometer, barometer, and temperature sensor) to ensure that each is operating as expected. This output can be configured as part of a binary output message from the IMU binary output group or appended to an ASCII output message or SPI message through the Communication Protocol Control register (Register 30).

Each bitfield value in the *ImuStatus* output (*GyroStatus*, *AccelStatus*, *MagStatus*, *PresTempStatus*) can be broken down into four different states:

- *NominalUpdated*: The sensor is operating as expected and the current output is a new measurement.
- *NominalNotUpdated*: The sensor is operating as expected, but the current output is not a new measurement. This can occur when the sampling rate of the sensor is lower than the IMU Rate.
- *Saturated*: The sensor is saturated and its current output measurement has been set to the maximum value measurable by the sensor.
- *Failed*: The sensor is experiencing a failure and its output should not be trusted.

For more information on extracting each of these bitfield values from the *ImuStatus* output, please refer to the VN-100 Interface Control Document.

4.1.2 AHRS Status Output

The *AhrsStatus* output is a bitfield output containing various status information for the AHRS filter. This output can be configured as part of a binary output message from the Common or Attitude binary output groups or appended to an ASCII output message or SPI message through the Communication Protocol Control register (Register 30).

The *AhrsStatus* output can be broken down into the following bitfield values:

- *AttitudeQuality*: This bitfield value provides an indication of the quality of the attitude solution and can be broken down into four different states: *Excellent*, *Good*, *Bad*, and *NotTracking*.
- *GyroSaturation*: This flag indicates that at least one axis of the gyroscope is currently saturated.
- *GyroSaturationRecovery*: This flag is used to indicate the AHRS filter is in the process of recovering from a gyro saturation event.
- *MagDisturbance*: This bitfield value indicates the level of magnetic disturbance that has been detected.
- *MagSaturation*: This flag indicates that at least one axis of the magnetometer is currently saturated.
- *AccelDisturbance*: This bitfield value indicates the level of acceleration disturbance that has been detected.

- *AccSaturation*: This flag indicates that at least one axis of the accelerometer is currently saturated.
- *KnownMagDisturbance*: This flag indicates that a known magnetic disturbance has been reported by the user and the magnetometer measurements are currently being tuned out by the AHRS filter.
- *KnownAccelDisturbance*: This flag is used to indicate that a known acceleration disturbance has been reported by the user and the accelerometer measurements are currently being tuned out by the AHRS filter.

For more information on extracting each of these bitfield values from the *AhrsStatus* output, please refer to the VN-100 Interface Control Document.

4.2 OPERATIONAL CHALLENGES

While the VN-100 has been designed to operate in a wide variety of applications and use cases, there are some operations that can pose more of a challenge for the sensor. This section details challenges that may arise during operation of the VN-100 as well as troubleshooting tips for the most commonly encountered issues.

4.2.1 Sustained Dynamic Acceleration

Applications that experience sustained dynamic accelerations can suffer degraded pitch and roll estimates if this acceleration due to motion is not accounted for. The VN-100 provides the ability to account for acceleration due to motion through its velocity aiding feature.

Challenge

Without any form of external compensation, the VN-100 does not have any means of knowing how it is moving relative to the fixed Earth. As such, it does not have any means of knowing what the actual acceleration of the body is. Since the accelerometer measures the effect of both gravity and acceleration due to motion, the standard AHRS algorithm has to make the assumption that the long-term acceleration due to motion is zero. With this assumption in place, the VN-100 has sufficient information to estimate the pitch and roll based on the measurement of gravity provided by the accelerometer. This assumption works very well for applications where the sensor does not experience any long-term acceleration, such as when it is used indoors or on a large marine vessel. Applications that sustain long-term accelerations due to motion, however, will experience a significant error in the pitch and roll solution because the assumption of zero body acceleration in the AHRS algorithm is constantly being violated.

Measured Acceleration in a Coordinated Turn

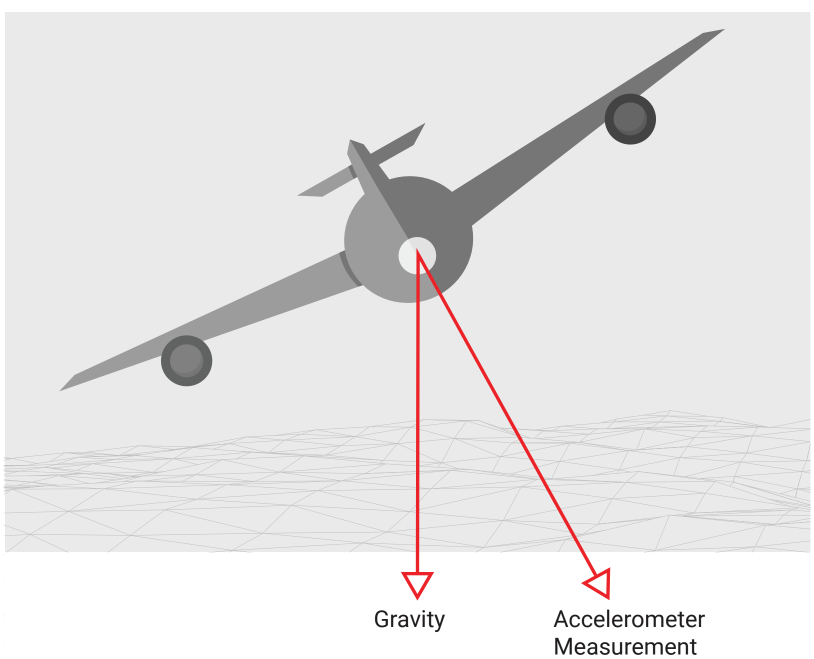


FIGURE 4.1

The most common case where this acceleration becomes a significant problem for an AHRS is when it is used on an aircraft operating in a banked turn. In straight and level flight, the AHRS will provide an accurate measurement of attitude as long as the long-term accelerations are nominally zero. However, when the aircraft banks and enters a coordinated turn, a long-term acceleration is present due to the centripetal force created by traveling along a curved path. The accelerometer will measure gravity plus this centripetal acceleration which results in a measurement vector that acts perpendicular to the wings of the aircraft as shown in Figure 4.1. This causes the VN-100 to estimate a roll angle of zero while the aircraft is in fact in a banked turn and thus has a significant roll angle relative to the horizon.

Mitigation

If the VN-100 can obtain some knowledge of the actual motion relative to the fixed Earth, then it is possible for the sensor to account for the effect of the centripetal acceleration, resulting in an accurate attitude estimation. The velocity aiding feature on the VN-100 provides a method to input real-time velocity estimates of the system allowing for the AHRS to estimate the centripetal acceleration term based on this velocity and the known body angular rates. The performance of the pitch and roll estimates will thus be improved through velocity aiding in applications experiencing sustained dynamic accelerations. Additional details on the velocity aiding feature can be found in TN005: Velocity Aiding.

4.2.2 Troubleshooting

If any issues are encountered during the setup or operation of the VN-100, some additional troubleshooting may be required. Below are a few of the most commonly encountered issues when using the VN-100. If the behavior persists after reviewing these troubleshooting tips, please reach out to VectorNav Support for additional assistance.

Heading is Incorrect

The VN-100 relies primarily on the onboard magnetometer for heading estimation. Unfortunately, deriving an accurate magnetic heading can be challenging in many real-world applications due to the presence of magnetic disturbances, which are magnetic fields created by objects nearby the sensor that bias and distort Earth's magnetic field. The magnetic-based heading estimate can be improved by:

- Mounting the VN-100 as far away from magnetic disturbances as possible
- Performing a hard and soft iron (HSI) calibration to account for magnetic disturbances that are rigidly mounted to the VN-100 and that do not vary over time
- Configuring the VPE heading mode for desired behavior in handling magnetic disturbances in the external environment surrounding the sensor

Heading is Drifting

The VN-100 should provide a drift-free attitude solution; however, there are conditions that can lead to drift in the estimated heading. If drift is present in the heading of the VN-100, it is recommended to:

- Check for an accelerometer and gyroscope bias by performing a bias calibration using the *Bias Calculator* tool in the VectorNav Control Center software. Unfortunately, all inertial sensor biases will drift over the life of the part regardless of the quality of the factory calibration. Reach out to VectorNav Support for more information on performing a bias calibration.
- Ensure that a valid hard and soft iron (HSI) calibration has been performed on the sensor as a poor HSI calibration can lead to drift in the magnetic-based heading estimate. More information on performing an HSI calibration can be found in TN002: Hard & Soft Iron (HSI) Calibration.
- Be sure that the VN-100 is mounted as far away from time-varying magnetic disturbances as possible such as motors running at different speeds or electronics turning on and off.
- Try using the VN-100 in a different environment to see if the drifting persists as the sensor may be operating in a poor magnetic environment.

Pitch/Roll is Incorrect

The VN-100 relies primarily on the onboard accelerometer in the pitch and roll estimation. If the pitch and/or roll estimate of the VN-100 is reporting an incorrect value, it is recommended to:

- Perform a bias calibration on the accelerometer using the *Bias Calculator* tool in the VectorNav Control Center software. Unfortunately, all inertial sensor biases will drift over the life of the part regardless of the quality of the factory calibration. Reach out to VectorNav Support for more information on performing a bias calibration.
- If the VN-100 experiences sustained dynamic motion, ensure that the velocity aiding feature is used to account for acceleration due to motion. Additional details on the velocity aiding feature can be found in TN005: Velocity

Aiding.

User-Configured Settings Erased After Power Cycle or Reset

In order for the user-configured settings to be saved to the non-volatile memory of the VN-100 and persist through a reset or power cycle of the sensor, a Write Settings command must be sent to the sensor after all desired settings have been configured.

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