ArNav User Manual

ARDICLABS

integrated sensing solutions

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Contents

1 INTRODUCTION

ArNav product family consists of different systems ranging from Attitude Heading Reference Systems (AHRS) to Double Antenna RTK GNNS/INS. Each product has been produced to serve different functions and accuracy requirements. ArNav products are inertial navigation systems produced by from Ardic Research and Development Corporation (ArdicLabs). All products contain a 3D inertial sensor assembly (gyroscopes and accelerometers), 3D magnetometer, static pressure and temperature sensor, with optionally one or two GNSS receivers in a compact and rugged enclosure.
The ArNav product line is composed of two main series, the ArNav S series and the ArNav M series. ArNav S series is a class of Micro-Electromechanical Systems(MEMS) based inertial sensors with low-cost, miniaturized form, entry level accuracy and limited range of interface options. ArNav M series is a class of Micro-Electromechanical Systems(MEMS) based inertial sensors with high accuracy, advanced functional options and wide range of interface options.
ArNav series have an embedded processor provides driftless and real-time navigation information over a wide range of temperature in dynamic and static conditions. Attitude Heading Reference Systems fuses accelerometer, gyroscope and magnetometer outputs in an optimal way to provide accurate roll, pitch and yaw. GNSS/INS systems also yield position and velocity. Double antenna GNSS/INS systems are designed to provide accurate heading data even if the system is static and/or the magnetic field is distorted.

1.1 ArNav S series

The ArNav S series is the entry level product of the ArNav family with 3 different products. ArNav S series consists of AHRS (ArNav S1A), GNSS/INS (ArNav S1G) and GNSS/INS with real-time kinematic capability (ArNav S1GR).

Figure 1: ArNav S series

1.1.1 ArNav S1A AHRS

ArNav S1A is a 3 DOF Attitude Heading Reference System (AHRS) which provides driftless real-time orientation information over the full 360°of angular motion on all three axes. It includes 3D accelerometers, 3D gyroscopes and 3D magnetometers.

1.1.2 ArNav S1G GNSS/INS

ArNav S1G includes all the functions of ArNav S1A, a GNSS receiver that can receive and track all four major GNSS constellations (GPS L1C/A, GLONASS L1OF, Galileo E1-B/C and BeiDou B1l) with an advanced Kalman filtering algorithm providing accurate 3D position, velocity and attitude. ArNav S1G is a state of the art GNSS/INS system.

1.1.3 ArNav S1GR RTK GNSS/INS

ArNav S1GR is the most sophisticated member of the ArNav S series, configured with a GNSS receiver that can receive and track all four major GNSS constellations (GPS L1C/A, GLONASS L1OF, Galileo E1-B/C and BeiDou B1l). ArNav S1GR thus not only outputs the all navigation data as in ArNav S1G, but also supports real time kinematic (RTK) function. RTK capability of ArNav S1GR enables RTCM data processing that yields highly accurate position/velocity and attitude solutions.

1.2 ArNav M Series

The ArNav M is the high performance series of the ArNav product family with 3 different products. The products offer different functions with different levels of filtering. ArNav M2 series consists of:
ArNav M2G: GNSS/INS
ArNav M2GR: Dual band, RTK GNSS/INS
ArNav M2HDR: Dual band, double antenna, RTK GNSS/INS.

The main SMA connector of the ArNav systems is labeled as GNSS A. For GNSS aiding and RTK solution, RF connector must be plugged in to GNSS A SMA connector.

Figure 2: ArNav M series

1.2.1 ArNav M2G GNSS/INS

ArNav M2G is an advanced GNSS aided inertial navigation system (INS) that provides accurate position, velocity, acceleration and attitude data under the most demanding conditions. It combines a high performance 3D inertial sensor assembly (gyroscopes and accelerometers), 3D magnetometer, static pressure, temperature sensor, with a GNSS receiver that can receive and track all four major GNSS constellations (GPS L1C/A, GLONASS L1OF, Galileo E1-B/C and BeiDou B1l) with an advanced sensor fusion algorithm. ArNav M2G provides accurate 3D position, velocity and attitude. ArNav M2G supports different user requirements with its unique and well-designed architecture.

1.2.2 ArNav M2GR Dual Band RTK GNSS/INS

ArNav M2GR contains all the capabilities of ArNav M2G. ArNav M2GR offers a fully integrated solution that employs an RTK capable multiple band GNSS receiver (L2OF, L2C, E1B/C, B2I, E5b, L1C/A, L1OF, B1I). Multiple band receiver with concurrent reception of GPS, GLONASS, Galileo and BeiDou tracking capability and the highly sophisticated algorithms embedded in ArNav M2GR offers up to 8mm position accuracy. ArNav M2GR accepts multi-band, multi-constellation RTCM data including GPS, GLONASS, GALILEO and BeiDou.

1.2.3 ArNav M2HDR Double Antenna GNSS/INS

ArNav M2HDR is a double antenna RTK GNSS aided inertial navigation system. Double antenna RTK GNSS is capable of tracking multiple band, multiple constellation (L2OF, L2C, E1B/C, B2I, E5b, L1C/A, L1OF, B1I). ArNav M2HDR provides very accurate pitch/yaw data under any circumstances using sophisticated algorithms exploiting the advantages of double antenna configuration.Moreover, RTK capability of the system enhances the position and velocity solutions up to centimeter level accuracy. ArNav M2HDR is the most advanced system of ArNav M series.

2 ArNav OPERATING PRINCIPLES

2.1 Kalman Filter and Aiding Mechanisms for AHRS

The ArNav AHRS products provide driftless real time orientation information over the full 360°of angular motion on all three axes. Orientation estimation is based on the integration of the rate of turn data (angular velocity data of the gyroscopes). Increasing errors stemming from this integration process are compensated using ArNav AHRS filter. ArNav AHRS filter is an Extended Kalman Filter (EKF) designed for orientation estimation. AHRS filter uses the measurement of gravity (accelerometer) and measurement of Earth magnetic north (magnetometer) to compensate gyroscope based errors and provide high accuracy driftless orientation output for both static and dynamic conditions.

2.1.1 Initialization

The ArNav S1A uses average of 3D accelerometers and 3D magnetometers readings to compute initial roll, pitch and yaw angles. The pitch and roll angles are initialized using accelerometer measured gravitational field vector, and yaw is initialized using magnetometer measured Earth's magnetic field. Initialization requires the vehicle to remain stationary after start-up in order to estimate the initial 3D attitude and remove the initial gyroscope bias errors with high performance. After the initialization, the system operates the AHRS filter and as the system experiences dynamics, the accuracy of the attitude solution increases. AHRS filter continues to estimate gyroscope biases during operation.

2.1.2 Accelerometer measurements

In the ArNav S1A, the gravity reference vector computed from accelerometer measurements provides a reference for the Extended Kalman Filter (EKF) when the AHRS is in quasi-static motion to correct roll and pitch angle drift and to estimate the x and y gyro bias. The EKF allows the attitude estimate to primary rely on angular rate sensors when the object is accelerating. In quasi-static motion, the feedback gains are increased and accelerometer measurements compensate the attitude errors and gyroscope biases. Better attitude accuracy is achieved during quasi-static motion and short-term dynamic situations. Long-term dynamic situations prevent the system to apply enough gyroscope bias correction and may decrease the attitude estimation performance.

2.1.3 Magnetometer measurements

The AHRS filter can estimate heading from magnetometer measurements. Magnetometer measurements are used to feed the EKF with yaw angle (heading) measurements. Magnetometer measures the earth's magnetic field and enables the system to compute yaw angle.
The Earth's magnetic field can be disturbed in proximity of large metal objects or external magnetic fields. The usage of this erroneous magnetometer measurements leads to attitude errors. ArNav products use an adaptive measurement process to reject the corrupted magnetometer data and prevent the yaw angle solution to deviate from the truth.

2.2 Kalman Filter and Aiding Mechanisms for GNSS Integrated Products

Strapdown navigation systems rely on rate and acceleration measurements and initial position and velocity information to provide position and velocity. Errors on sensor readings caused by bias, scale factors, thermal/magnetic effects, other nonlinearities and initialization offsets cause an accumulation in navigation errors and navigation solution drifts with time. Increasing errors of strapdown navigation is compensated using ArNav's GNSS/INS Extended Kalman Filter (EKF). The position, velocity, attitude and sensor errors of the GNSS/INS are estimated using the EKF. The EKF works in a two-step process. In the prediction step, the EKF produces position, velocity and attitude estimates along with their uncertainities by integrating the sensor outputs over time. Due to small errors associated with the gyroscope and accelerometer outputs, the estimates will also be erroneous and the uncertainities associated with the estimates will grow with time. In the correction step of the EKF, the error on the estimates is corrected and associated uncertainty is decreased. There exist different types of sensors used for EKF measurements in ArNav GNSS/INS systems to improve the accuracy of the inertial navigation. These are baro-altimeter, magnetometer, non-holonomic constraints and GNSS receivers.

2.2.1 GNSS aiding

ArNav's GNSS integrated systems include different types of GNSS receivers, all of which are multi-constellation and some are also multi-band. In the systems, GNSS generates position and velocity outputs with bounded errors. Using GNSS position and velocity solutions, the EKF generates the corrections for diminishing the position, velocity, attitude and sensor errors. As a result, the overall GNSS integrated system output is driftless and has a bounded uncertainty. In other words, the system benefits from the bounded error characteristics of the GNSS and high frequency characteristics of the INS at the same time by integrating them. EKF is able to estimate states with indirect measurements. As a result, GNSS velocity and position measurements are used to estimate errors on attitude, and sensor errors indirectly while position and velocity errors are compensated directly. Type of movement and dynamics of the application are effective on the quality of Kalman filter estimated errors. As an example, applications with high dynamics allow accurate estimation of heading, while it is difficult to have accurate heading solution in a nonmoving platform.

2.2.2 Barometric height

The barometer measures the atmospheric pressure. Height derived from the barometric pressure is known as orthometric height. Orthometric height is the altitude over mean sea level (geoid), while GNSS height is the altitude over WGS-84 ellipsoid. EKF estimates this difference once the GNSS signal is acquired. GNSS/INS height solution is defined as WGS-84 height. EKF, using barometric height measurement, estimates the constant bias error and height drift caused by pressure changes. Apart from estimating bias and drift errors, barometric height measurement is used to estimate the velocity and acceleration errors in the vertical channel and increases the vertical channel accuracy and provides long-term stability. Barometric pressure to barometric altitude conversions is done using the 1976 US Standard Atmosphere in the systems. Deviations from standard values are estimated in the system.

2.2.3 Magnetometer measurements

Magnetometer measurements are used to feed the EKF with yaw angle (heading) measurements. Magnetometer measures the earth's magnetic field and enables the system to compute yaw angle. ArNav products use an adaptive measurement process to reject the corrupted magnetometer data and prevent the yaw angle solution to deviate from the truth. All GNSS integrated products contain a 3D magnetometer.

2.2.4 Nonholonomic constraints

Nonholonomic constraints use vehicle characteristics to improve attitude and heading estimations in land vehicle applications. When a vehicle does not slip and jump off the ground, the velocity of the vehicle in plane perpendicular to the longitudinal axis is zero. Nonholonomic constraints use this fact to aid the navigation system. It is assumed that motion along the lateral direction and motion normal to road surface are negligible. These constraints are not suitable for 3D airborne and helicopter applications. The forward axis (x) of the navigation system should be exactly aligned within 1 degree in the direction of the vehicle before turning nonholonomic constraints option on.

2.2.5 GNSS based heading

GNSS based heading aiding mechanism directly feeds the heading information derived from GNSS velocity. The aiding mechanism works when the vehicle moves with a horizontal speed of over 3 m/s. Heading is estimated using GNSS course over ground. As in the nonholonomic constraint, the forward axis (x) of the navigation system should be exactly aligned within 1 degree in the direction of the vehicle before turning GNSS based heading option on. GNSS based heading is immune to magnetic interference and calibration is not required. GNSS velocity vector should be aligned with the x-axis of the navigation system to use GNSS based heading measurement effectively. This measurement should not be used in helicopter and 3D airborne applications. Flying without magnetometer aiding and with no maneuver for a long time may degrade the heading accuracy of the system. GNSS based heading limits the heading divergence under these circumstances. Thus, this measurement may be used in 2D airborne applications if the magnetometer cannot be calibrated. It should be noted that user must calibrate the magnetometer for a better performance. It is also important to keep in mind that GNSS/INS system not using magnetometers and GNSS based heading provides accurate heading solution when there exists lateral maneuvers during the flight.

2.2.6 Double antenna GNSS heading

In GNSS/INS systems, heading accuracy decreases when the motion is on a straight line or the system is stationary. Under these circumstances, the magnetometers embedded in the system may maintain heading accuracy. However, the magnetometer cannot show the required performance in every environment. High electrical fields, metal surfaces cause magnetic deviations, reducing the reliability of magnetometer measurements. The system needs a continuous calibration and some errors are so variable that it cannot be completely eliminated by calibration. For these reasons, the use of magnetometers is not possible in all cases.
ArNav M2HDR is a double antenna RTK GNSS aided inertial navigation system. ArNav M2HDR exploits carrier phase measurements to provide very accurate heading data under any circumstances using sophisticated algorithms exploiting the advantages of double antenna configuration. As a result, ArNav M2HDR is capable of maintaining highly accurate heading data even under low dynamic situations.

2.2.7 GNSS receivers

ArdicLabs uses 2 types of GNSS receivers in their products. Receivers support different types of GNSS signals and different navigation functions. These receivers can be classified with respect to signals they can track as:

- GNSS receiver with concurrent reception capability of GPS (L1C/A), GLONASS (L1OF), Galileo (E1-B/C), BeiDou (B1I) GNSS signals. Does not support RTK operation.
- Multi-band GNSS receiver with concurrent reception capability of GPS (L1C/A, L2C), GLONASS (L1OF, L2OF), Galileo (E1B/C, E5b), BeiDou (B1I, B2I). Supports RTK operation.

All the receivers contain GNSS constellation settings and dynamic platform models in order to adjust the signals and the model used in the navigation engine. The default constellation setting is arranged as maximum constellation reception and the dynamic platform model is set to **Automotive** (see Table 12). These settings can be configured by the user.

2.2.8 Real time kinematic GNSS aiding

Real Time Kinematic (RTK) enabled ArNav products accept RTCM data in order to enable internal RTK calculations. As a result, GNSS receivers tracking L1 signals can provide positioning accuracy of 2.5 cm while the receivers tracking L1/L2 signals provide positioning accuracy of 1cm. Depending on the product model, RTK enabled ArNav systems use one of these receivers. The RTK enabled GNSS/INS system attains very high position, velocity and orientation accuracy via use of RTK GNSS position in EKF as measurement.

2.2.9 Loss of GNSS

In the GNSS/INS systems, if the GNSS signal is lost for a few tens of seconds, GNSS/INS switches to the AHRS mode. At this mode, the system integrates the IMU supplied angular rate data to calculate the orientation of the system and supplies the 3D magnetometer data and 3D accelerometer data to the Kalman filter. Kalman filter uses these measurements to stabilize the attitude and heading of the system and to reduce the gyroscope errors. If the magnetometer data is not available or heavily corrupted, the heading angle solution depends solely on z-gyroscope.

2.2.10 Aiding modes

For the ArNav GNSS/INS products, there are different aiding mechanisms. The aiding mechanisms given in Section 2.2 are optional and may be activated according to the needs of specific applications. The performance of the aiding mechanisms differs with respect to the environmental conditions and dynamics. For example, nonholonomic constraints may increase the performance of the system in an automotive application while may decrease the performance dramatically if they are applied in a vessel on the sea. Recommended aiding configurations and the related applications associated to the GNSS/INS products may be given as:

- **Aerospace Application:** Magnetometer measurements are used to determine accurate heading information. Nonholonomic constraint is off.
- **Land Application:** Nonholonomic constraint assuming the velocity vector of the vehicle is aligned with the direction of heading is employed to improve attitude and heading estimations. GNSS velocity measurements make the heading solution more accurate as long as the total velocity is over 5 m/s. When the system moves slowly or becomes static, the heading begins to diverge as until a speed over 5 m/s is experienced. Magnetometer is off.

The user may activate any aiding mechanism. If the system has double antenna GNSS, GNSS based heading aiding is operational by default. It is critical to activate the relevant aiding mechanisms in order to obtain maximum performance from the GNSS/INS system. For example, activating nonholonomic constraint or velocity heading in a helicopter application may disturb navigation solution in an unpredictable way.

Barometer aiding stabilizes the vertical channel in the absence of GNSS signals. Calibrating barometer with respect to local weather conditions makes the barometric altitude measurements more accurate. Especially, for the objects flying nap of the earth, activating barometer aid may prevent the vehicle from a crash in the case of long term GNSS signal loss and is strongly advised.

2.3 Initialization

2.3.1 Roll/pitch initialization

Alignment technique used in the ArNav systems is adjusted with respect to aiding modes. In all modes, the ArNav uses average of 3D accelerometers readings to compute initial roll and pitch angles. The pitch and roll angles are initialized using accelerometer measured gravitational field vector. Initialization requires the vehicle to remain stationary after start-up in order to estimate the initial roll/pitch and remove the initial x/y-gyroscope bias with high performance. Random accelerations may cause the initial roll/pitch estimates to be inaccurate and the correction may take several seconds.

2.3.2 Navigation initialization

The GNSS/INS systems have no position and velocity solution when powered up. Navigation initialization can be performed using GNSS navigation solution. GNSS position and velocity solutions are transferred to the system to set the initial position and velocity of the system as soon as GNSS 3D fix signal is available.

2.3.3 Heading initialization

Heading initialization may be completed using different sources and techniques. User may choose one of the following in order to initialize the heading.

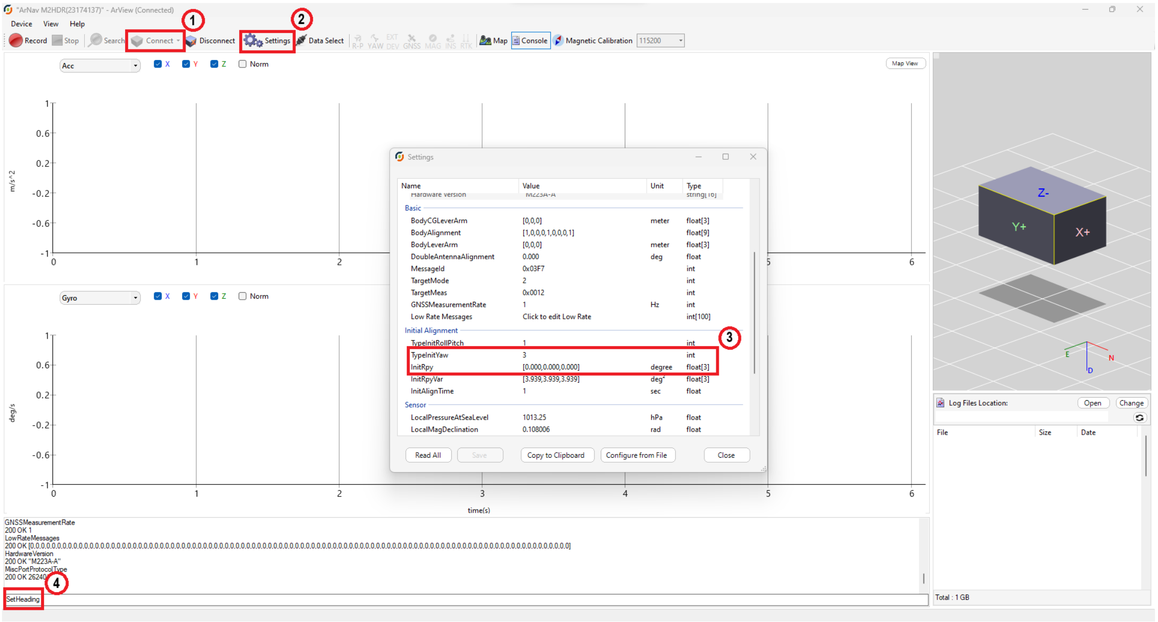
- **External heading:** In ArNav, the user may align the system with external heading. Selecting external heading option enables user to feed the system with heading information. In this approach, the yaw angle (heading) and its uncertainty are entered to the system by the user. The associated standard deviation should reflect the quality of the yaw angle input for optimal navigation performance. If the quality of the yaw input is uncertain, it is best to feed a higher standard deviation to the system. After the alignment, the accuracy of the attitude solution increases as the system experiences dynamics. It is important to note that external heading should be the heading of the platform coordinate frame with respect to the navigation coordinate frame.
- **Magnetic heading:** Initial heading alignment technique differs with respect to user's choice. When the magnetic heading is selected for heading initialization, yaw is initialized using the 3D magnetometer measured Earth's magnetic field. When the magnetometer is enabled, it is the default source for initial heading. Initialization requires the vehicle should remain stationary after start-up for at least 3 seconds in order to estimate the yaw and remove the initial gyroscope bias with high performance. However, the quality of attitude and gyroscope bias estimation increases as the standing stationary time increases. It should be noted that the usage of erroneous magnetometer measurements leads to yaw errors and calibration is required at every installation change. User should depend on magnetometer for initial heading estimation if and only if the magnetometer is calibrated, respectively.
- **Velocity heading:** If the velocity heading is selected for initialization, the velocity information from the GNSS is used to align the INS while in motion. The heading alignment will be activated once the vehicle reaches 5 m/s (18 km/h) and heading is estimated using GNSS course over ground. The roll/pitch of the system is initialized by the accelerometer derived roll/pitch angles when the system is stationary. Once the kinematic alignment is finished, the system is switched to the navigation filter.
- **Double antenna heading:** In ArNav M2HDR, if the double antenna heading is selected for initialization, the carrier phase difference from two GNSS antennas are used to solve the initial heading with high accuracy. Depending on the length of baseline, heading accuracy may vary. It is important to note that direction from base to rover antenna should be aligned to X axis of the navigation system. GNSS lever arm vector is given to the system with respect to the rover antenna.
- **External magnetic heading:** In ArNav systems, user can feed the system with magnetic data with external magnetometer. When the external magnetometer heading option is selected, ArNav system calculates heading with the external magnetometer data. External magnetic data can be feed to system by ArNavPro V2.0 Interface. With the help of magnetic norm information, ArNav system can scale the measurements and determine the yaw angle.

  Once the alignment is finished, the system is switched to the navigation filter.

When initial heading type is chosen “by GNSS” or “by double-antenna”, GNSS/INS doesn’t work until the system gets heading data. To put the system GNSS/INS mode, initial heading value can be set by the user. The following steps can be followed to set heading.

1. Set the initial heading parameter with “InitRpy = [Roll Value,Pitch Value, Heading Value]” command and save.
2. Type SetHeading to the console. (0x53 0x65 0x74 0x48 0x650x 61 0x64 0x69 0x6e 0x67 0x0d 0x0a in hex format)
3. If system reads the command properly it will return “200 OK Setting Heading\r\n” (0x32 0x30 0x30 0x20 0x4f 0x4b 0x20 0x53 0x65 0x74 0x74 0x69 0x6e 0x67 0x20 0x48 0x65 0x61 0x64 0x69 0x6e 0x67 0x0d 0x0a in hex format)

Example implementation for SetHeading command in the ArView Software is shown in figure below.



Settings

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BodyAlignment	[1,0,0,0,1,0,0,0,1]		float[9]
BodyLeverArm	[0,0,0]	meter	float[3]
DoubleAntennaAlignment	0.000	deg	float
MessageId	0x03F7		int
TargetMode	2		int
TargetMeas	0x0012		int
GNSSMeasurementRate	1	Hz	int
Low Rate Messages	Click to edit Low Rate		int[100]
Initial Alignment			
TypeInitRollPitch	1		int
TypeInitYaw	3		int
InitRpy	[0.000,0.000,0.000]	degree	float[3]
InitRpyVar	[3.939,3.939,3.939]	deg²	float[3]
InitAlignTime	1	sec	float
Sensor			
LocalPressureAtSeaLevel	1013.25	hPa	float
LocalMagDeclination	0.108006	rad	float

```
GNSSMeasurementRate
200 OK 1
LowRateMessages
200 OK [0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0]
HardwareVersion
200 OK "M223A-A"
MiscPortProtocolType
200 OK 26240
```

```
SetHeading
```

Figure 3: SetHeading Using ArView

3 MAGNETOMETER CALIBRATION

Magnetometer measures the Earth's magnetic field and enables the system to compute heading. However, magnetic sensors are sensitive to the surroundings, and the magnetic data is affected. The magnetic sensors should be compensated in order to overcome environmental magnetic effects and ensure accurate heading solutions.

All of the ArNav products compensate the soft iron and hard iron effect using only the Earth's magnetic field vector and a compensation algorithm. The systems collect a series of measurements and send these to magnetic calibration algorithm. The algorithm allows the determination of the hard iron and soft iron parameters at the same time. Calibration process takes only a few minutes and the computed values are then stored to the navigation system.

Hard iron distortion is produced by materials in the vicinity of magnetic sensors and exhibits an additive field to the Earth's magnetic field. Soft iron distortion is the result of material that influences the magnetic field in a way that is dependent upon the orientation of the material relative to the sensor and changes the direction of the magnetic field.

ArView includes 2D and 3D magnetic calibration algorithms. The magnetic calibration process has the following steps:

1. Installing ArNav product to the platform in which it is used
2. Collecting magnetic sensor data(online)/Reading from a preloaded file(offline)
3. Processing measured data by Magnetic Calibration Software
4. Setting the calibration parameters in the ArNav product

The magnetic calibration procedure may be online or offline. Either the product can be directly connected to a computer for online data collection or it is possible to calibrate the system using data from a log file. A log file may be generated by the user manually. The magnetic calibration steps are explained in the following sections.

3.1 Installing ArNav

ArNav is installed into the location where it is used. Ensure that the location does not possess time varying magnetic fields or moving magnetic material. ArNav should be rigidly fixed to guarantee that it cannot move during calibration and operation.

The ArNav magnetic calibration procedure should be repeated when

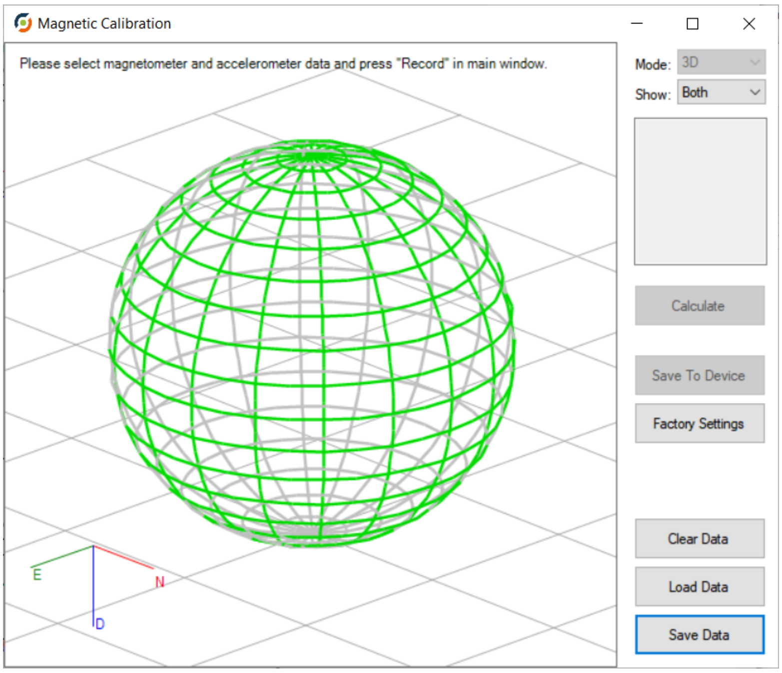
- ArNav is removed.
- The magnetic materials and electrical devices surrounding the ArNav are replaced.
- ArNav is reinstalled.

3.2 Data Collection

ArView allows the user to implement 2D or 3D calibration. It is strongly advised to collect the magnetometer data according to the application. If application includes pitch angle changes (as in air vehicles), it is strongly advised to run 3D calibration. On the other hand, 2D calibration is adequate for automotive applications.

For 3D calibration, ArNav x-axis should be steered on the surface of an imaginary sphere and collect magnetic sensor data from the different points of this sphere. Magnetic calibration accuracy increases as the

ArNav travels all around the sphere. Theoretically, 12 magnetic measurements from different orientations are enough, however, it is strongly advised to collect more data for higher accuracy.
During the 2D calibration procedure, ArNav should make a series of measurements while the platform it is installed in, turns through a complete 360 degree circle. Platform alignment Section 4.2.6 of the system which experiences a 2D calibration should be kept constant during the calibration and operation. Otherwise, ArNav will produce false navigation results when the magnetometer is on. It is important to note that during data collection, the system should move sufficiently slow and should be kept stationary if possible.


Please select magnetometer and accelerometer data and press "Record" in main window.

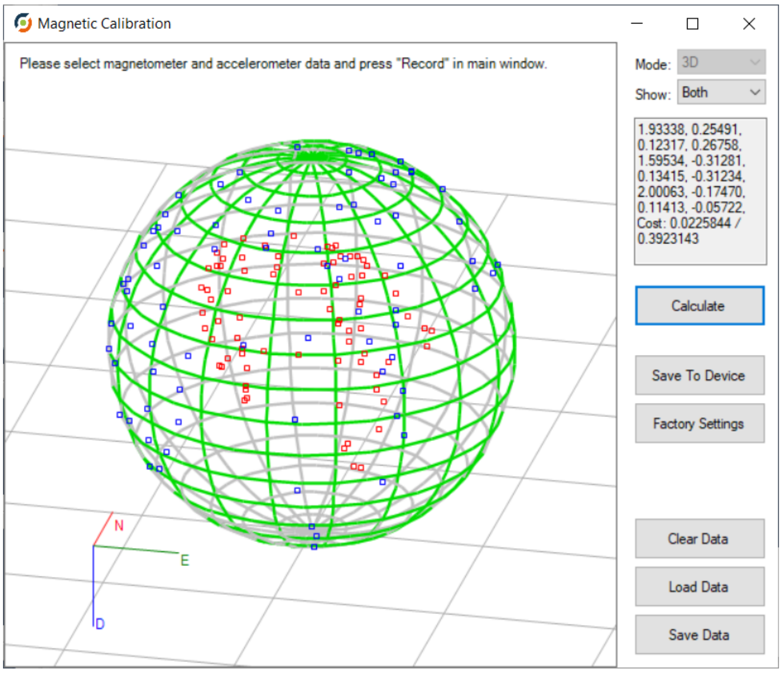
Mode: 3D

Show: Both

Figure 4: Magnetic calibration data collection

3.3 Data Processing

Calibrate button activates the calibration algorithm that determines the hard iron and soft iron effects existing around the ArNav. Calibration results are given by a 3x3 matrix and a 3x1 offset vector given in the calibration window. The quality of the calibration is also presented in terms of remaining attitude error (Figure 5).



Please select magnetometer and accelerometer data and press "Record" in main window.

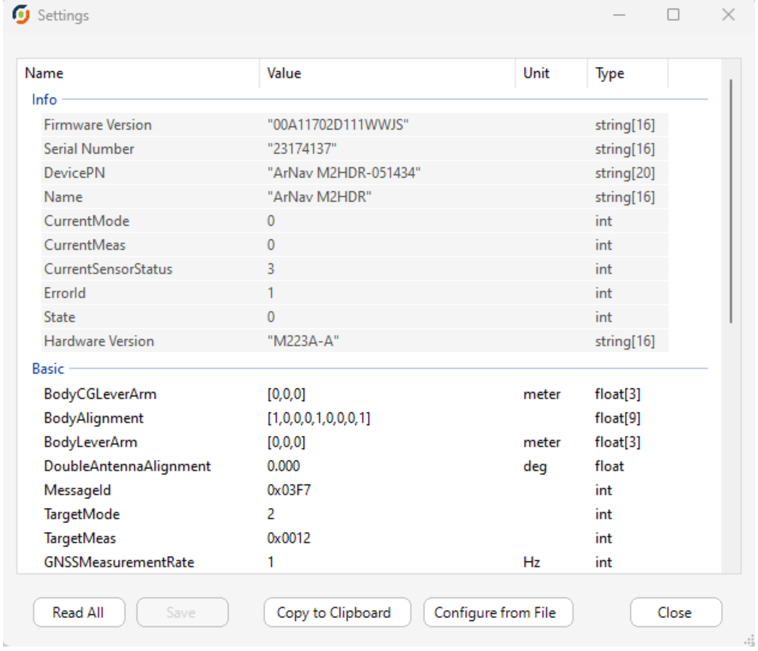
Mode: 3D

Show: Both

```
1.93338, 0.25491,
0.12317, 0.26758,
1.59534, -0.31281,
0.13415, -0.31234,
2.00063, -0.17470,
0.11413, -0.05722,
Cost: 0.0225844 /
0.3923143
```

Figure 5: Calibration results

ArNav is set with the calibration results given in the calibration window using the Device Settings window (Figure 6) of the ArView. Details of the user interface may be found in **ArView User Manual**.



Name	Value	Unit	Type
Info			
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Serial Number	"23174137"		string[16]
DevicePN	"ArNav M2HDR-051434"		string[20]
Name	"ArNav M2HDR"		string[16]
CurrentMode	0		int
CurrentMeas	0		int
CurrentSensorStatus	3		int
ErrorId	1		int
State	0		int
Hardware Version	"M223A-A"		string[16]
Basic			
BodyCGLeverArm	[0,0,0]	meter	float[3]
BodyAlignment	[1,0,0,0,1,0,0,0,1]		float[9]
BodyLeverArm	[0,0,0]	meter	float[3]
DoubleAntennaAlignment	0.000	deg	float
MessageId	0x03F7		int
TargetMode	2		int
TargetMeas	0x0012		int
GNSSMeasurementRate	1	Hz	int

Figure 6: Device settings window

4 DATA SPECIFICATION

This section has been provided to clarify the definitions of data that are output by the ArNav products. Details on data outputs, output protocol and HEX output are given in Section 5.

4.1 Coordinate Systems

Precise definition of Cartesian coordinate systems is crucial to understand the system outputs. The sensors embedded in the system and the system itself measure and calculate the outputs with respect to some defined coordinate system. The coordinate frames employed in the system are the body frame and the local-level frame.

4.1.1 ArNav body frame

This coordinate frame has its origin at the center of the navigation system. Xb-axis points towards the roll, Y_b-axis is towards the pitch axis according to right handed system and Z_b-axis is pointing down (yaw axis) as shown in Figure 7.

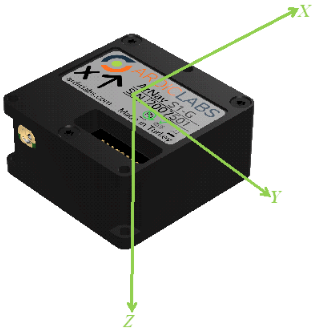


Figure 7: ArNav body coordinate system

3D sensors in the system are mounted in an orthogonal geometry and the orthogonality of the sensors are also ensured by highly sophisticated factory calibration process. The aluminum chassis and the sensors in the system are aligned to the body frame ($X_b - Y_b - Z_b$) within $< 0.1°$accuracy.
Moreover, 3D acceleration, 3D rate of turn and 3D magnetometer readings are also maintain orthogonality in between each axis within $< 0.1°$.

4.1.2 Earth centered inertial (ECI) frame

Newton has defined the inertial frame as a frame which does not accelerate or rotate. The Newtonian equations of motion are defined based on this frame. Inertial frame is impossible to realize in practice and the best approximation to such a frame is according to the distant stars which can be assumed motionless.
In the navigation systems, the inertial frame is described with respect to the earth. Such a frame is called Earth Centered Inertial (ECI) frame (Figure 7). In the ECI frame, the origin is at the center of the earth, X_i-axis is positive towards the intersection point of Greenwich meridian and equator at t0, Z_i-axis lies along the North Pole at t0, Y_i-axis is defined to complete a right-handed orthogonal coordinate system. The inertial sensors provide measurements of body motion with respect to inertial frame.

4.1.3 Earth centered earth fixed (ECEF) frame

ECEF coordinate system is a right-handed earth fixed system shown in Figure 8. As seen in the figure, the origin is the earth center of mass, Z_e-axis has a direction toward North Pole and X_e-axis is directed through the intersection of Greenwich and the plane passing through the origin and normal to the Z_e-axis. Y_e-axis completes a right-handed earth fixed coordinate system. This frame rotates with the earth and coincides with ECI frame every 24 hours. This coordinate system approximates the earth as an ellipsoid which is known as WGS 84 ellipsoid. Any position in this coordinate system can also be defined by the geodetic parameters of latitude (φ), longitude (λ) and height (h) over the WGS-84 ellipsoid. The ArNav GNSS/INS systems output the position in WGS-84 geodetic coordinates unless otherwise specified.

WGS-84 models the Earth's shape as an ellipsoid known as WGS-84 ellipsoid. This is an ellipsoid with the semi-major axis a (6,378,137.0 m) and the semi-minor axis b (6,356,752.3142 m).

4.1.4 Navigation frame

The navigation (local-level) frame has its origin at the location of the ArNav navigation system and the axes lie along north (N-X_n), east (E-Y_n) and local normal to the ellipsoid, down (D-Z_n) as seen in Figure 8. The angular rate of the NED frame with respect to earth, known as the transport rate, is determined by the motion of the navigation system with respect to the earth. ArNav's orientation and velocity outputs are calculated with respect to NED frame. The velocity is output as north, east and down velocity unless otherwise specified.

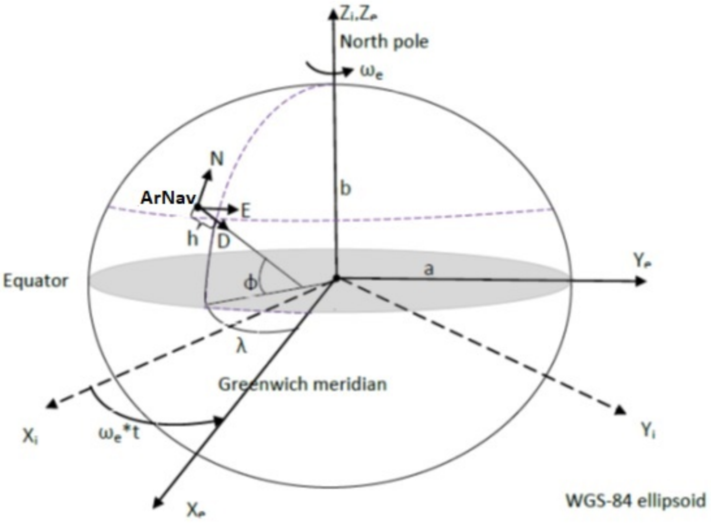


Figure 8: Body frame and platform frame

4.2 Navigation Data

4.2.1 Position and velocity representation

ArNav GNSS/INS outputs the position solutions in WGS84 coordinates as latitude (rad), longitude (rad) and height (m). The velocity is provided as North, East and Down velocity (m/s).

4.2.2 Orientation representation

The orientation calculated by the ArNav is the orientation of the body coordinate system (b) with respect to the local-level (n) coordinate system. There exist a number of orientation representations available. All representations provide identical results regardless of their implementation differences. ArNav outputs the orientation using the following representations:

- Euler angles (roll,pitch,yaw)
- Quaternions (Euler symmetric parameters)

A brief description on these representations is given in following sections.

4.2.2.1 Euler angles

Euler angles are three independent parameters which define the position of a reference axis system relative to a new one. The Euler angles represent the conventional roll-pitch-yaw angles. Unfortunately, the definition of Euler angles is not unique and depends on the axes about which the rotations are carried out, and their sequence. Different representations are defined with different rotation orders. That is, a different representation can be defined with an interchange in the order of rotation.
In order to define the angles which transform a vector from reference to a new axes system, a series of three right-handed rotations are employed and the reference is coincided with the new system. In 321 rotation order, first a right-handed rotation ψ is applied on z-axis, until it coincides with z-axis of the new axis. In the second rotation applied on the resultant set of axes, the resultant y-axis is rotated until it coincides with y-axis of the new axis. The amount of this rotation is assigned to θ , pitch angle. Finally, the third rotation about the x-axis by the angle ϕ , the roll angle, moves the reference system to the new coordinate system.
As a result, the three rotations with the order of ψ,θ,ϕ (yaw, pitch, roll) bring the system to the orientation of new coordinate system. The total transformation matrix is composed of three separate transformation matrices. The transformation matrices C_1, C_2, C_3 for rotations about the z-axis, about the y-axis, about the x-axis may be expressed as below, respectively.

$$\mathbf{C}_1 = \begin{pmatrix} cos\psi & sin\psi & 0 \\ -sin\psi & cos\psi & 0 \\ 0 & 0 & 1 \end{pmatrix}, \mathbf{C}_2 = \begin{pmatrix} cos\theta & 0 & sin\theta \\ 0 & 1 & 0 \\ sin\theta & 0 & cos\theta \end{pmatrix}, \mathbf{C}_3 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & cos\phi & sin\phi \\ 0 & -sin\phi & cos\phi \end{pmatrix}.$$

Taking the reference frame as navigation (local-level) frame and the resultant frame as body frame, the resultant transformation matrix, is composed of the individual transformation matrices given above:

$$\mathbf{C}_n^b = \mathbf{C}_1\mathbf{C}_2\mathbf{C}_3$$

$$\mathbf{C}_n^b = \begin{pmatrix} cos\theta cos\psi & cos\theta sin\psi & -sin\theta \\ cos\psi sin\theta sin\phi & cos\psi cos\phi + sin\psi sin\theta sin\phi & cos\theta sin\phi \\ cos\psi sin\theta cos\phi + sin\psi sin\phi & -cos\psi sin\phi + sin\psi sin\theta cos\phi & cos\theta cos\phi \end{pmatrix}$$

and

$$\mathbf{C}_b^n = \mathbf{C}_n^b, \mathbf{C}_b^n\mathbf{C}_n^b = \mathbf{I}$$

The Euler angle representation becomes undefined when the pitch angle, is 90°. Euler angles are expressed in radians.

4.2.2.2 Quaternions

The rotation from one frame to another is achieved by a single rotation about quaternion vector in the quaternion representation. Hamilton quaternion algebra, which realizes the rotation vector idea, uses a 4x1 vector $\mathbf{q}(q_0, q_1, q_2, q_3)$ known as quaternion vector, instead of three ordered rotations (Euler angles) for coincidence of two coordinate frames. The quaternion is defined as a hypercomplex number of the form:

$$\mathbf{Q} = q_0 + q_1\mathbf{i} + q_2\mathbf{j} + q_3\mathbf{k}$$

where q_0, q_1, q_2, q_3 are real numbers, and $1, \mathbf{i}, \mathbf{j}, \mathbf{k}$ forms a basis for a quaternion vector space. In the above representation, q_0 , defines the amount of the rotation about a vector represented by q_1, q_2, q_3. As a result, quaternion vector can be described as:

$$q_0 = cos\tfrac{\mu}{2}$$

$$q_1 = sin\tfrac{\mu}{2}cos\alpha$$

$$q_2 = sin\tfrac{\mu}{2}cos\beta$$

$$q_3 = sin\tfrac{\mu}{2}cos\gamma$$

where μ is the amount of rotation and α, β, γ are the angles between the axis of rotation and the coordinate system. Quaternion parameters satisfy a single constraint equation:

$$\mathbf{QQ*} = q_0^2 + q_1^2 + q_2^2 + q_3^2$$

and

$$\mathbf{R}_n = \mathbf{QR}_b\mathbf{Q*}$$

where n and b stand for the navigation and the body frame and the body to navigation transformation matrix is

$$\mathbf{C}_b^n = \begin{pmatrix} q_0^2 + q_1^2 - q_2^2 - q_3^2 & 2(q_1q_2 - q_0q_3) & 2(q_0q_2 + q_1q_3) \\ 2(q_1q_2 + q_0q_3) & q_0^2 - q_1^2 + q_2^2 - q_3^2 & 2(q_2q_3 - q_0q_1) \\ 2(q_1q_3 - q_0q_2) & 2(q_0q_1 + q_2q_3) & q_0^2 - q_1^2 - q_2^2 + q_3^2 \end{pmatrix}$$

Quaternion elements in terms of the direction cosine matrix elements are as follows:

$$q_0 = \tfrac{1}{2}\sqrt{C_{11} + C_{22} + C_{33} + 1}$$

$$q_1 = \tfrac{C_{32} - C_{23}}{4q_0}$$

$$q_2 = \tfrac{C_{13} - C_{31}}{4q_0}$$

$$q_3 = \tfrac{C_{21} - C_{12}}{4q_0}$$

4.2.3 Calibrated sensor measurements

The effects of external factors on the sensors are calibrated in order to obtain the maximum navigation performance from the system. The nature of the relation between sensor outputs and physical variables such as temperature, time, vibration and g-dependence is modeled with a number of laboratory tests and the following model obtained can be used to calibrate the inertial (g,a) and magnetic (m) sensors.

$$y_k = S_k M_k u_k + b_k, \qquad k = sensor(g,a,m)$$

$$u_k = \begin{pmatrix} u_{kx} \\ u_{ky} \\ u_{kz} \end{pmatrix}, \quad y_k = \begin{pmatrix} y_{kx} \\ y_{ky} \\ y_{kz} \end{pmatrix}, \quad b_k = \begin{pmatrix} b_{kx} \\ b_{ky} \\ b_{kz} \end{pmatrix}$$

$$S_k = \begin{pmatrix} S_{kx} & 0 & 0 \\ 0 & S_{ky} & 0 \\ 0 & 0 & S_{kz} \end{pmatrix}, M_k = \begin{pmatrix} m_{k,11} & m_{k,12} & m_{k,13} \\ m_{k,21} & m_{k,22} & m_{k,23} \\ m_{k,31} & m_{k,32} & m_{k,33} \end{pmatrix}$$

In the above model, y_k is the sensor output and u_k is the true value. Orthogonality errors in between the sensors and misalignment of the sensor axes with respect to body axes is modeled in the misalignment matrix, M_k . S_k is the gain matrix, b_k is the sensor bias values. The above model can be simplified as

$$y_k = H u_k + b_k$$

ArNav calibrates the sensors using this model and obtains the calibrated sensor outputs as follows:

$$u_k = H^{-1}(y_k - b_k)$$

The real model used for calibration is much more complicated and includes effects such as temperature, g-dependence etc. Electrical parameters (S_k and b_k) change with the temperature, so the gain matrix and the bias values are modelled with respect to temperature during the extensive laboratory tests.

4.2.4 Status

Status shows if GNSS is on, GNSS/INS is running and magnetometer measurements are valid.

4.2.5 GPS 1PPS

GPS 1PPS is output from the system as synchronization signal.

4.2.6 Platform alignment matrix

Heading alignment with GNSS velocity and the nonholonomic constraints assume that the motion of the vehicle is coincident with the navigation system's forward axis. Otherwise, navigation performance significantly degrades, even destabilizes. The forward axis (X) should either be exactly aligned within 1°in the direction of the vehicle or the orientation of the system with respect to the vehicle (platform alignment) should be determined and set. Details on platform alignment matrix, transforming the vectors in body frame to the vehicle (platform) frame, are given in this section.

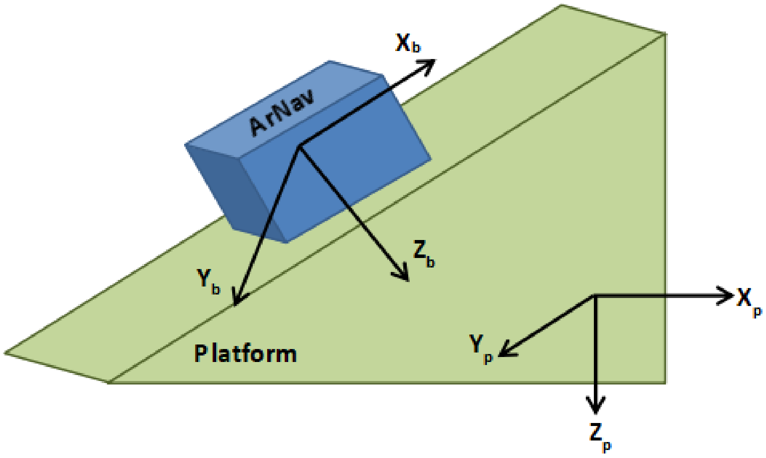


Figure 9: Body frame and platform frame

The body to platform frame transformation matrix, $\mathbf{C}_b^p$, should be set in order to use the kinematic alignment and nonholonomic constraints in above vehicle (Figure 9). Platform coordinate system is a right handed coordinate system. Any vector in body frame can be transformed to platform frame as:

$\mathbf{R}_p = \mathbf{C}_b^p \mathbf{R}_b$
where p and b stand for the platform and the body frame, respectively. The body frame is set to be exactly aligned with the vehicle (platform) frame in factory. Default transformation matrix

$$\mathbf{C}_b^p = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

and the platform coordinates are coincident with the body coordinates. However, user can set the relative orientation with "*BodyAlignment*" matrix. As a result, the orientation output of the navigation system is the orientation of the platform coordinate system (p) with respect to the local-level (n) coordinate system. This is

$$\mathbf{C}_p^n = \mathbf{C}_b^n \mathbf{C}_b^{pT}$$

The navigation system transforms body fixed IMU measurements, accelerations and rotation rates, to the platform frame before using in any of the navigation calculations. Thus, all the outputs of the system are provided with respect to the platform coordinate system centered at ArNav's center.

4.2.7 Antenna position definition

The ArNav GNSS/INS and the GNSS antenna cannot be located at the same position, physically. The distance between the GNSS antenna phase center and the IMU (body frame) center is the GNSS antenna lever arm. For example, in automotive applications, the GNSS antenna is usually mounted on the roof of the vehicles while the ArNav GNSS/INS is located inside and the position that is calculated by the INS is different from the GNSS position by the vector of the GNSS antenna lever arm. The lever arm should be compensated for increasing the accuracy of the system. Otherwise, the integrated system solutions will shift from the true trajectory. Thus, GNSS measurements at the antenna are translated into the IMU location. The GNSS lever arm vector is provided to the system by ”*BodyLeverArm*” parameter as the difference between IMU center location and the GNSS antenna location in the platform coordinate system(Figure 10). The lever arm vector between GNSS antenna and IMU is expressed in platform coordinates as follows:

$$\mathbf{LA}_p = \begin{pmatrix} LA_x \\ LA_y \\ LA_z \end{pmatrix}$$

GNSS/INS assumes that the lever arm is fixed and does not change during the operation. It is advised to input the lever arm vector with 5 cm accuracy whenever it changes not to degrade the system performance.

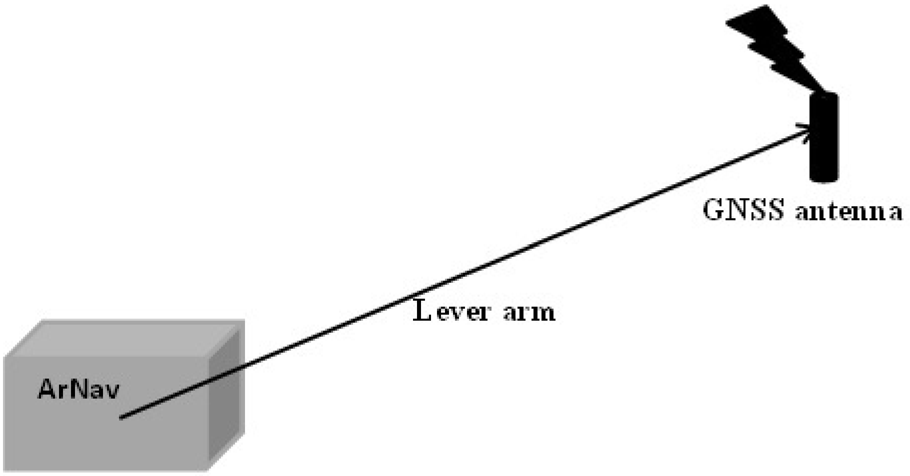


Figure 10: GNSS antenna and the system

4.2.8 Center of Gravity position definition

User may require to have the navigation data from center of gravity of the platform which is usually a point other than where the ArNav system is located. The distance between the center and the Center of Gravity is the CoG lever arm.

For example, in unmanned aerial vehicles, the navigation system is usually mounted on a location other than CoG. However, user may need to use navigation data (eg. acceleration for autopilot development) from CoG of the platform.

In order to have the position, velocity, attitude and acceleration of CoG, user should enter the GNSS/INS to CoG position difference vector using ”*BodyCGLeverArm*” parameter. Thus, GNSS/INS measurements at the system location are translated into the CoG location.

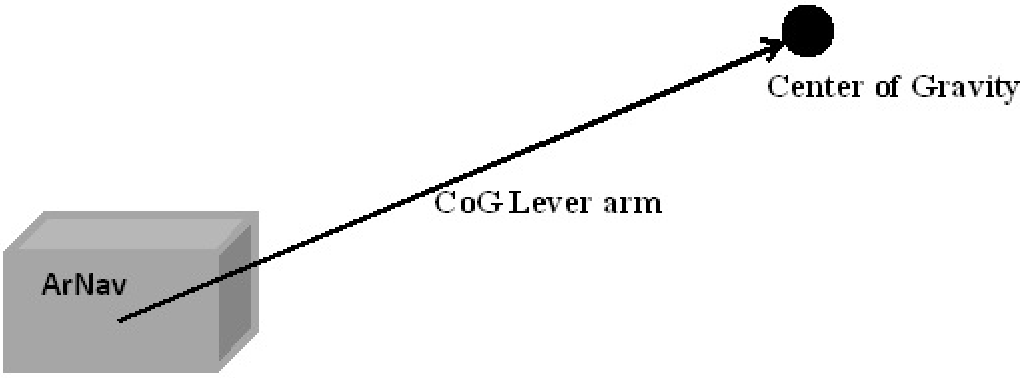


Figure 11: Center of gravity and the system

4.2.9 Double antenna alignment

Heading with double antenna systems assume that the vector from base to the rover antenna is coincident with the navigation system's forward axis. The forward axis (X) should either be exactly aligned within 1°in the direction of the vehicle or angle of the antenna vector (from base to rover) with respect to the body X axis should be determined and set. This angle is set by "*DoubleAntennaAlignment*" parameter and is clockwise positive. Otherwise, the navigation system may destabilize.

4.2.10 Low Rate Messages

Low Rate Message consist of 3 floats. First float is for message information and the other two floats are for data, unless otherwise stated. First float consists of 32 bit unsigned int. With following data:

8 Bit Unsigned Int	8 Bit Unsigned Int	8 Bit Unsigned Int	8 Bit Unsigned Int
Message ID	Reserved	Data Rate	Data Slot

Low Rate Message IDs are given in Table 15. These messages include GNSS, GNSS/INS and External Device information that are generated at a low rate. Low rate message structure is formed as 2x32 bit at 100 Hz.
Every parameter given in Table 15 are 32 bit. User may select all necessary messages at an appropriate rate from the Table. For example, GNSS validity is generated at 1-5 Hz and may be required by the user at that rate using the relative ID. Details of the low rate message structure is given in Section 5.

4.3 Performance Specification

4.3.1 ArNav performance specification

ArNav product family consists of different systems ranging from Attitude Heading Reference Systems (AHRS) to Double Antenna GNSS/INS. The ArNav product line is composed of two main series, the ArNav S series and the ArNav M series. ArNav S series is a class of MEMS based systems with low-cost, miniaturized form, entry level accuracy and limited range of interface options. ArNav M series is a class with high accuracy, advanced functional options and wide range of interface options. The performance characteristics of the products are given in Table 1.

Table 1: ArNav performance

	ArNav M Series	ArNav S Series
Output Update Rate	100 Hz	100 Hz
Roll, Pitch Accuracy	0.1°	0.2°
Heading Accuracy (GNSS & Dynamic)	0.2°	0.4°
Heading Accuracy (Magnetometer/Double Antenna)	1° / 0.1 ° (>2 meter antenna separation)	1° / NA
Pressure Altitude Accuracy	$<$ 10 m (with baro setting)	$<$ 10 m (with baro setting)
Position Accuracy (Horizontal-Vertical)	2.0 m-2.5 m	2.0 m - 2.5 m
Position Accuracy (with RTK)	0.02 m-0.03 m	0.1 m-0.15 m
Velocity Accuracy	0.05 m/s	0.05 m/s
Velocity Accuracy (with RTK)	0.007 m/s	0.01 m/s

*NA: not applicable

4.3.2 Sensor performance specification

4.3.2.1 Inertial sensors

Performance parameters of inertial sensor suites in ArNav M and ArNav S series are given in Table 2.

Table 2: Inertial sensor performances

	ArNav M Series		ArNav S Series	
Sensors	Accelerometers	Gyroscopes	Accelerometers	Gyroscopes
Measurement range	±40g	±500°/s	±6g	±250°/s
Bias repeatability	1.5g	0.14°/s	20 mg	1°/s
Bias in-run stability	13μg	2.7°/hr	0.2 mg/°C	0.015 °/s/C°
Scale factor	$<$ 0.04 %	$<$ 0.03 %	0.02 %/C°	(1+0.02 /C°) %
Noise density	70 μg/$\sqrt{Hz}$	0.004°/s/$\sqrt{Hz}$	190 μg/$\sqrt{Hz}$	0.014°/s/$\sqrt{Hz}$
Nonlinearity	<0.03%FS	<0.01%FS	<0.5%FS	<0.05%FS
Alignment error (RMS)	1 mrad	1 mrad	8 mrad	10 mrad
Bandwidth	140 Hz	140 Hz	40 Hz	47 Hz

4.3.2.2 Magnetometer

ArNav M and ArNav S series use identical magnetometers with the performance parameters given in Table 3.

Table 3: Magnetometer performance

ArNav Series Magnetometer	
Measurement range	± 8 G
RMS error	0.4 mGauss
Nonlinearity	$<$ 0.2 %
Resolution	0.4 mGauss

4.3.2.3 Barometer

Performance parameters of barometers in ArNav M and ArNav S series are given in Table 4.

Table 4: Barometer performance

	ArNav M	ArNav S
Measurement range	300-1100 hPa	260 - 1260 hPa
RMS noise	0.08 hPa	0.01 hPa

5 SERIAL COMMUNICATION PROTOCOL

All ArNav devices have at least one RS232 and one RS422 communication port. Also all devices have a timepulse sync signal from GNSS and one general purpose I/O pin. Depending of the device version additional RS232, CAN bus and two GPIO ports can be supported by a secondary connector. Pin description is given in Section 7.1.2.
Default serial configuration for both RS232 and RS422 ports are:

- Baud rate: 115200
- Data bits: 8.
- Stop bits: 1.
- Parity: None.
- Flow control: None.

5.1 Data Messages

Data messages begins with 4 bytes of preamble and Message Id. Message Id describes which data is in the message. Length of the payload depends on the Message Id. Message ends with 2 bytes of CRC. Example source code for CRC calculation is given in Appendix A and Appendix B for ‘C’ and ‘C Sharp’ programming languages. Default MessageId is 723. Integer values are in little endian. Float values are in IEEE-754 Single precision 32-bit format.

Table 5: Message Structure

Preamble	Message Id	Data	Checksum
1 Byte 0x3D(61)	3 Bytes	Variable Length	2 Bytes

5.1.1 Description of MessageId

```
message[0] = 0x61
MessageId = (message[1] << 8) | message[2];
message[3] is reserved and set to 0.
```

5.1.2 Bits of MessageId

Table 6: Message Id Structure

Bit Position	Data Description	Unit	Format	Number of Bytes
Id & 0x0001	Acceleration (XYZ)	m/s^2	3 x Float	12
Id & 0x0002	Gyro (XYZ)	rad/s	3 x Float	12
Id & 0x0004	Magnetometer (XYZ)	Normalized to 1	3 x Float	12
Id & 0x0008	Latitude longitude elevation data	$rad-rad-m$ (WGS84)	3 x Float	12
Id & 0x0010	Roll, Pitch, Yaw	$radian$	3 x Float	12
Id & 0x0020	Pressure, Temperature, Baro Height	$millibars,C,m$	3 x Float	12
Id & 0x0040	Time (Device time from start)	$seconds$	1 x Float	4
Id & 0x0080	Status	see Table 7	8 Bits	1
Id & 0x0100	Velocity	North East Down velocity(m/s)	3 x Float	12
Id & 0x0200	Scaled LLh	$rad-rad-m$ Latitude and Longitude scaled by 536870912, height scaled by 16384	3 x Integer	12
Id & 0x1000	Low Rate Messages	N/A	4 Byte + 2 x Float	12

Table 7: Status Bits Description

Bit Position	Name	Description
Status & 0x01	System_State	1 if System is OK, 0 if not
Status & 0x02	RollPitch_State	1 if Roll and Pitch angles are valid, 0 if not
Status & 0x04	Yaw_State	1: Heading solution is valid 0: not valid
Status & 0x08	PosVel_State	1 if Position and Velocity are valid, 0 if not
Status & 0x10	Mag_State	1 if Magnetometer measurement is in vicinity of Earth's Magnetic Field, 0 if not
Status & 0x60	GNSS_State	0: GNSS not fixed 1: GNSS fixed 2: Differential GNSS (RTK) solution: Float 3: Differential GNSS (RTK) solution: Fixed
Status & 0x80	Reserved	-

Table 8: Examples of MessageId

MessageId	Data
0xD3(211)	Acc, Gyro, Euler, Time, Status
0xC7(199)	Acc, Gyro, Magn, Time, Status
0xF8(248)	Euler, Latitude Longitude Altitude, Pressure, Time, Status

Listing 1: Example bit stream

```
3d                                        //Preamble
02 d3 00                                  //Message Id
7e 4c 4b bc 01 cc a9 bc 4e a6 1d 41       //Acc
a8 75 cc 3c 7b 7c 86 bc d1 80 33 bd       //Gyro
aa 04 1b 40 76 07 78 3e e5 95 ba 40       //Euler
d4 c5 41 41                               //Time
0c                                        //Status
a6 90 78 a8 71 e8 30 b8 61 ff 28 fc       //SLlh
94 81                                     //CRC
```

- First 4 bytes is preamble with messageId (0x02d3) information.
- The next 4 bytes “7e 4c 4b bc” is binary presentation value of floating value: -0.012408373877740612.
- The last 2 bytes are CRC code. CRC code examples are given in Appendix A and Appendix B.

5.2 Configuration Messages

Configuration messages are in text(Ascii) format and with variable size. Configuration messages end with “\r\n” (13 10)
Messages are split in three categories: “Command”, “Parameter Request” and “Parameter Set”. If command is successful, device returns “200 OK\r \n” message. If an error occurs, device returns “4XX Error description\r\n” like: “405 Undefined param\r \n”

5.2.1 Commands

Command messages are as follows:

Table 9: Command Messages

Command	Description
params	Requests all available parameters on the device.
save	Save parameters on device.
reset	Resets the device.

5.2.2 Parameter Request

Typing the name of the parameter with “\r \n” returns the value of parameter.

- If type of the parameter is int or float and size of parameter is 1, the device returns: 200 OK value\r \n.
- If type of the parameter is string, the device returns: 200 OK “value”\r \n.
- If type of the parameter is int or float and size of parameter is more than 1, the device returns: 200 OK [value1, value2, value3, ... valueN]\r \n.

Table 10: Example of Parameter Read Messages

Command	Device Response
State\r \n	200 OK 0\r \n
DeviceSN\r \n	200 OK ”19270002”\r \n
LocalMagField\r \n	200 OK [0.25224, 0.02585, 0.40487]\r \n

5.2.3 Parameter Set

Typing the name of the parameter with “=” and the value of the parameter with “\r \n” sets the value of parameter. Device returns: 200 OK\r \n on success.

- If type of the parameter is int or float and size of parameter is 1, parameter = value\r \n.
- If type of the parameter is string, parameter = “value”\r \n.
- If type of the parameter is int or float and size of parameter is more than 1, the device returns: 200 OK [value1, value2, value3, ... valueN]\r \n.

Table 11: Example of Parameter Set Messages

Command	Device Response
State=1\r \n	200 OK\r \n
LocalMagField = [0.25224, 0.02585, 0.40487]\r \n	200 OK\r \n

5.3 ArNav Series Parameters

Table 12: ArNav Parameters

Name	Type	Size	Values	Description
HardwareVersion	char	16	e.g. “M220D-A-T”	Device hardware version
FirmwareVersion	char	16	e.g. “00A001000010773B”	Device firmware version
DeviceSN	char	16	e.g. “20350008”	Device unique serial number
DevicePN	char	20	e.g. “ArNav M2HDR-051294”	Device production number
DeviceName	char	16	e.g. “ArNavM2-HDR”	Device name
MiscPortBaudRate	int	1	[1]: 9600 [2]: 19200 [3]: 38400 [4]: 57600 [5]: 115200 [6]: 230400 [7]: 460800 [8]: 921600	Baud rate of 3 ports are adjusted using this command. Baud rate parameters [int] are concatenated and transformed to HEX as in the below example. Example: Port 1 = 1 (9600 bps) Port 2 = 4 (57600 bps) Port 3 = 2 (19200 bps) MiscPortBaudRate = 0x00020401 (dec:132097)
CurrentMode	int	1	[0]: VRU [1]: AHRS [2]: GNSS/INS [3]: INS	Current running mode of system.
TargetMode	int	1	[1]: AHRS **[2]: GNSS/INS**	Target running mode of system.
TargetMeas	int	1	see Table 27	AHRS or GNSS/INS target measurements as selected by user
CurrentMeas	int	1	see Table 27	Current running measurements. This can differ from TargetMeas. For example, the user may include the magnetometer in the TargetMeas, but it is not included in CurrentMeas if the magnetometer is not calibrated properly
CurrentSensorStatus	int	1	Not Defined	N/A, for future use
BodyCGLeverArm	float	3	**[0,0,0] (m)**	Length between sensor module and Center of Gravity
BodyAlignment	float	9	**[1,0,0,0,1,0,0,0,1]**	Platform alignment matrix
BodyLeverArm	float	3	**[0,0,0] (m)**	Length between sensor module and GNSS antenna
TypeInitRollPitch	int	1	[0]:initRollPitchUser **[1]=initRollPitchImu**	Use initial roll and pitch angle from user[0] or IMU[1]
TypeInitYaw	int	1	[0]:initYawUser **[1]:initYawMag** [2]:initYawGNSSVel [3]:initYawDoubleAntenna [4]:initYawExternalMag**[p1]**	Initial yaw angle from user[0], from magnetometer[1], GNSS velocity[2], double antenna heading[3] or from an external magnetometer[4]
InitRpy	float	3	**[0,0,0]** (rad)	Initial roll, pitch and yaw angles. Usage depends on the selection of *typeInitRollPitch* and *typeInitYaw*
InitRpyVar	float	3	**[0.03,0.03,0.03]** rad^2	Variance of user defined initial roll, pitch and yaw angles

Table 13: Parameters

Name	Type	Size	Values	Description
InitAlignTime	float	1	**3** (sec)	Initial alignment time
LocalPressureAtSeaLevel	float	1	**1013** (hPa)	Local pressure
LocalMagDeclination	float	1	**0.1024** (rad)	Local magnetic declination
LocalHGeoid	float	1	**34.911** (m)	Local geoid height (WGS84)
CalibMag	float	12	**[1,0,0,0,1,0,0,0,1,0,0,0]**	Magnetometer calibration matrix
DoubleAntennaAlignment	float	1	**1.57** (rad)	Angle between antenna vector and X axis
LLHHeightType	int	1	**[0]: llhHeightTypeWGS84** [1]: llhHeightTypeMSL	Height type
PortInOutConfig	int	1	Reserved	Reserved
State	int	1	[0]: Not send output **[1]: Send output data**	Device data output state
MessageId	int	1	see Table 6	Output messages
GNSSDynModel	int	1	[0]: gnssDynModelPortable [2]: gnssDynModelStationary [3]: gnssDynModelPedestrian **[4]: gnssDynModelAutomotive** [5]: gnssDynModelSea [6]: gnssDynModel1g [7]: gnssDynModel2g [8]: gnssDynModel4g	Dynamic model setting for GNSS receiver
GNSSFixMode	int	1	[1]: gnssFixMode2d **[2]: gnssFixMode3d** [3]: gnssFixModeAuto	Position fixing mode
GNSSMeasurementRate	int	1	**[1]: gnssMeasurementRate1** [5]: gnssMeasurementRate5	GNSS measurement rate (1 Hz or 5 Hz)
MiscPortProtocolType	int	1	**[1]: ArNavInOut** [4]: GNSSAidInOut [6]: ExtAidIn[p1]	Protocol types of 3 ports are adjusted using this command. Port protocol types of each port are concatenated and transformed to HEX as in the below example. Example: Port 1: ArNavInOut =1 Port 2: GNSSAidInOut=4 Port 3: ArNavInOut =1 PortProtocolType = 0x00010401 (dec:66561)

Table 14: CurrentMeas and TargetMeas Bits Description

Bit Position	Name	Description
TargetMeas & 0x0001	Reserved1	-
TargetMeas & 0x0002	AHRS_Mag	Use Magnetometer for heading
TargetMeas & 0x0004	Reserved2	-
TargetMeas & 0x0008	Reserved3	-
TargetMeas & 0x0010	GNSS/INS_Baro	Include Barometer into altitude
TargetMeas & 0x0020	GNSS/INS_Mag	Include Magnetometer into heading
TargetMeas & 0x0040	GNSS/INS_GNSSHeading	Use GNSS velocity for heading
TargetMeas & 0x0080	Reserved4	-
TargetMeas & 0x0100	GNSS/INS_DoubleAntenna	Use double antenna GNSS heading
TargetMeas & 0x0200	Reserved5	-
TargetMeas & 0x0400	GNSS/INS_NonHolonomicConstraint	Use nonholonomic constraint for land applications
TargetMeas & 0xFF80	Reserved6	-

Table 15: Low Rate Message Description

ID	Name	Description	Data Type
0	GNSS _ TIMEDIFFFROM1PPS _ COUNTER	GNSS solution time from 1PPS signal (ms)	Float & Float
1	GNSS_ITOW_NUMBEROFSV	Number of SVs used for navigation	Float & Float
2	GNSS_VALIDITY_HEIGHT	GNSS height (m) solution validity	Float & Float
3	GNSS_LAT_LON	GNSS latitude and longitude solution (rad)	Float & Float
4	GNSS_VELNORTH_VELEAST	GNSS north and east velocity solution (m/s)	Float & Float
5	GNSS_ACCURACY_HORIZONTAL_VERTICAL	GNSS horizontal and vertical position accuracy (m)	Float & Float
6	GNSS_VELDOWN_ACCURACYSPEED	GNSS down velocity solution and GNSS speed accuracy (m/s)	Float & Float
7	GNSS_GDOP_PDOP	Geometric Dilution of Precision and Position Dilution of Precision	Float & Float
8	NAV_ACCURACY_LAT_LON	GNSS \INS latitude and longitude accuracy (m)	Float & Float
9	NAV_ACCURACY_H_VDOWN	GNSS \INS altitude (m) and down velocity accuracy (m/s)	Float & Float
10	NAV_ACCURACY_VNORTH_VEAST	GNSS \INS north and east velocity accuracy (m/s)	Float & Float
11	NAV_ACCURACY_ROLL_PITCH	GNSS \INS roll and pitch accuracy (rad)	Float & Float
12	NAV_ACCURACY_YAW_RESERVED	GNSS\INS yaw accuracy (rad)	Float
13	NAV_ESTBIAS_ACCX_ACCY	Estimated bias of x and y accelerometers (m/s^2)	Float & Float
14	NAV_ESTBIAS_GYROX_GYROY	Estimated bias of x and y gyroscopes (rad/s)	Float & Float
15	NAV_ESTBIAS_ACCZ_GYROZ	Estimated bias of z accelerometer (m/s^2) and z gyroscope (rad/s)	Float & Float
16	SYSTEM_STATUS_LOG	Status control message of the system. Reserved: Uint8 Bit Field IMU Status: Uint32 Bit Field [Table 17] Magnetometer Status: Uint8 Bit Field [Table 18] Barometer Status: Uint8 Bit Field [Table 19] GNSS Status: Uint8 Bit Field [Table 20]	Uint64
20	GNSSDOUBLE_RELPOSNEDFLAG_LENGTH	Double antenna baseline length (m)	Float & Float
21	GNSSDOUBLE_RELPOSNEDHEADING_ACCURACY	GNSS double antenna heading accuracy (deg)	Float & Float
22	GNSSDOUBLE_RELPOSNEDNORTH_EAST	Relative position of rover antenna wrt. base antenna in north and east (m)	Float & Float

Table 16: Low Rate Message Description (Continiued)

ID	Name	Description	Data Type
40	TIME_UTC	UTC Time consists of 64 bit data Struct_Time_UTC 8 Bit Unsigned Int: Reserved 16 Bit Unsigned Int: Year 8 Bit Unsigned Int: Month 8 Bit Unsigned Int: Day 8 Bit Unsigned Int: Hour 8 Bit Unsigned Int: Minute 8 Bit Unsigned Int: Seconds	UTC Time Structure
41	LOCAL_GEOIDUNDULATION_RESERVED	Difference in height between the geoid and the Earth's reference ellipsoid. First float sends geoid undulation, second float is reserved.	Float
42	CURRENTMODE_RESERVED	Current mode is last byte of 4 byte data [Table 21] Current Mode = 0: VRU Current Mode = 1: AHRS Current Mode = 2: GPS/INS Current Mode = 3: INS	Uint8

The message IDs' specified with square brackets will be described in the Section 5.3.1.

5.3.1 Detailed Description

ID: 16 System Status Log
Status of the sensors are represented with bit fields. Bit Fields for IMU, Magnetometer, Barometer and GNSS are given tables below. Keep in mind that first byte is reserved.

Table 17: SYSTEM_STATUS_LOG IMU Status Bit Field Description

Field	Bit Count
IMU Ready Field	1
IMU Initial Alignment Fail Field	1
Accelerometer Fail Field	1
Gyroscope Fail Field	1
IMU CRC Fail Field	1
IMU Synchronization Fail Field	1
IMU CRC Fail Count Field	9
IMU CRC Synchronization Count Field	9
Reserved	1

Table 18: SYSTEM_STATUS_LOG Magnetometer Status Bit Field Description

Field	Bit Count
Magnetometer Ready Field	1
Magnetometer Read Valid Data Field	1
Reserved	6

Table 19: SYSTEM_STATUS_LOG Barometer Status Bit Field Description

Field	Bit Count
Barometer Ready Field	1
Barometer Read Valid Data Field	1
Reserved	6

Table 20: SYSTEM_STATUS_LOG GNSS Status Bit Field Description

Field	Bit Count
GNSS1 Ready Field	1
GNSS2 Ready Field	1
Reserved	6

ID: 42 Current Mode
First three bytes are reserved. The last byte describes the current mode. Byte structure is shown in Table 21.

Table 21: Data 1 of CURRENTMODE_RESERVED Description

Reserved	Reserved	Reserved	Current Mode

5.4 ArNavPro V2.0 Interface

This section aims to explain the ArNavPro V2.0 messages structure. This protocol can be use to aid navigation system with external data. The ArNavPro V2.0 protocol is valid for firmware version 20000$^{\mathbf{p1}}$ and later.

Data messages begin with 1 bytes of preamble and Message Id. Message Id describes which data is in the message. The message structure of ArNavPro V2.0 Interface is shown in the table below. Message ends with 2 bytes of CRC. All protocol messages use little endian format.

Table 22: ArNavPro V2.0 Message Structure

Preamble (1 Byte)	Message Id (3 Byte)	Payload Length (2 Byte)	Payload	Checksum (2 Byte)

5.4.1 Data Messages

Table 23: Data Messages

Message ID	Message Name	From	To
0x010001	Magnetic Field Data	External Device	ArNav
0x010002	Magnetic Field Data Extended	External Device	ArNav

5.4.1.1 (0x010001) Data:Magnetic Field

Table 24: Message Description: Magnetic field data

Preamble (1 Byte)	Message Id (3 Byte)	Payload Length (2 Byte)	Payload	Checksum (2 Byte)
0x3D	0x010001	0x000D	See below	CRC

Table 25: Payload Description

Byte Offset	Type	Name	Description
0	U1 bit_0 : bit_1 : bit_2 : bit_3 : $bit_{4\text{-}5}$: $bit_{6\text{-}7}$:	dataInfo validX validY validZ useData devId reserved	Control flag of Magnetic Field data validity of X axis validity of Y axis validity of Z axis Use valid measurement data Set to ‘b00’ Set to ‘b00’
1	R4	magX	Magnetic Field X (Gauss)
5	R4	magY	Magnetic Field Y (Gauss)
9	R4	magZ	Magnetic Field Z (Gauss)

5.4.1.2 (0x010002) Data:Magnetic Field Extended

To aid external magnetic field data to navigation system, at least one valid Data:Magnetic Field Extended message must be sent from external device to navigation system. Local magnetic norm, external device alignment and time synchronization information received from this message. After one valid Data:Magnetic Field Extended message, only Data:Magnetic Field can be send to navigation system up to 15Hz.All information is save volatile memory and assumed to valid until system reset or system power off.

Table 26: Message Description: Magnetic field data

Preamble (1 Byte)	Message Id (3 Byte)	Payload Length (2 Byte)	Payload	Checksum (2 Byte)
0x3D	0x010002	0x005E	See below	CRC

Table 27: Payload Description

Byte Offset	Type	Name	Description
0	U1 bit_0 : bit_1 : bit_2 : bit_3 : $bit_{4\text{-}5}$: $bit_{6\text{-}7}$:	dataInfo validX validY validZ useData devId reserved	Control flag of Magnetic Field data validity of X axis validity of Y axis validity of Z axis Use valid measurement data Set to ‘b00’ Set to ‘b00’
1	R4	magX	Magnetic Field X (Gauss)
5	R4	magY	Magnetic Field Y (Gauss)
9	R4	magZ	Magnetic Field Z (Gauss)
13	R4	normMagField	Norm of local magnetic field (Gauss)
17	R4[9]	alignMat	Magnetometer alignment w.r.t platform [a0 a1 a2 ; b0 b1 b2; c0 c1 c2]
53	U1 $\text{bit}_{0\text{-}3}$: $\text{bit}_{4\text{-}7}$:	tovType allTovType reserved	Time of validity w.r.t ‘b0000’: Tov type not defined for devId ‘b0001’: Use (received-syncTime) time ‘b0010’:Reserved ‘b0011’: Reserved ‘b0000’
54	I4	syncTime	Time from Synchronization (1e-7 second) Not defined for tovType ‘b0000’. Positive means; validity time of received is before synchronization signal time
58	R4[9]	Reserved	Set to zeros.

5.4.1.3 *Data Message Examples:*

Listing 2: Example bit stream of data magnetic field message

```
3d              //Preamble
01 00 01        //Message Id
0D 00           //Message Length
0F              //Data Info
2F 8A FD 3E     //Magnetic Field X (0.495194882)
A5 EE 4E 3E     //Magnetic Field Y (0.202082232)
B6 81 1B BF     //Magnetic Field Z (-0.607447982)
94 81           //CRC
```

Listing 3: Example bit stream of data magnetic field extended message

```
3d                 //Preamble
02 00 01           //Message Id
5E 00              //Message Length
0F                 //Data Info
2F 8A FD 3E        //Magnetic Field X (0.495194882)
A5 EE 4E 3E        //Magnetic Field Y (0.202082232)
B6 81 1B BF        //Magnetic Field Z (-0.607447982)
60 42 E5 3E        //Norm of local magnetic field (0.44777203)

00 00 80 3F
00 00 00 00
00 00 00 00
00 00 00 00
00 00 80 3F        //Alignment Matrix = [1,0,0;0,1,0;0,0,1]
00 00 00 00
00 00 00 00
00 00 00 00
00 00 80 3F

01                 //Time of Validity Type (0x01)
40 42 0F 00        //Sync Time (1000000)

00 00 00 00
00 00 00 00
00 00 00 00
00 00 00 00
00 00 00 00        //Reserved = [0,0,0;0,0,0;0,0,0]
00 00 00 00
00 00 00 00
00 00 00 00
00 00 00 00

72 9C              //CRC
```

6 ArView SOFTWARE

ArView PC Software can be used to configure ArNav devices and view navigation data. Latest version of the ArView PC Software can be downloaded from company website https://ardiclabs.com/downloads.html. ArView PC Software supports following features:

- Magnetic Calibration
- Data View
- Device Settings
- 3D View
- Data Record and Log Browser

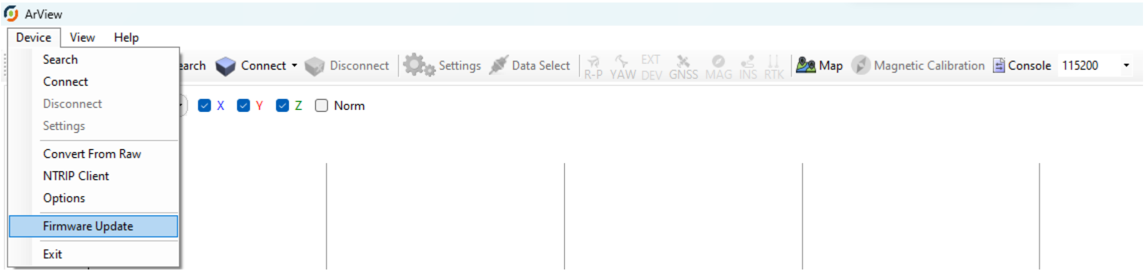
Information about ArView Pc Software is given in ArNav Application Software documents.

6.1 Firmware Update

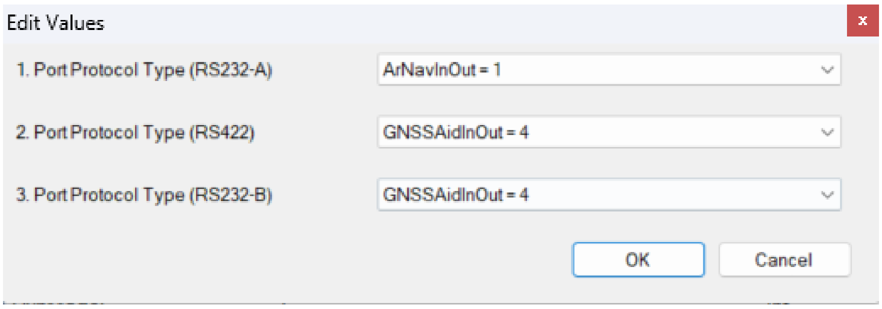
- Arview must be opened.

  Note: To perform firmware update, the system must be disconnected.

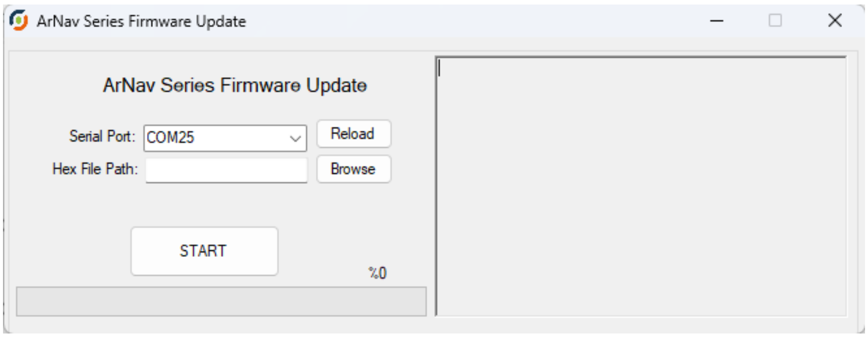
- Firmware update must be selected under ‘Device’ section.



- The relevant port that supports the RS-232 protocol must be selected. In the example below, COM25 communicates with RS-232, and the connected system’s RS-232 is set to ’ArNavInOut.


Edit Values

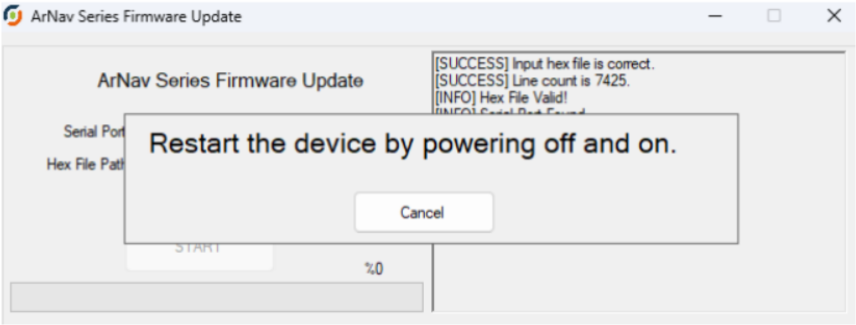
1. Port Protocol Type (RS232-A) ArNavInOut = 1
2. Port Protocol Type (RS422) GNSSAidInOut = 4
3. Port Protocol Type (RS232-B) GNSSAidInOut = 4



Serial Port: COM25

- Click the ’Start’ button to initiate the firmware update.
- The system must be restarted by powering it off and on within 2 seconds.

  Note: It is not recommended to cut off the system’s power by unplugging the connector cable from the USB port.



```
[SUCCESS] Input hex file is correct.
[SUCCESS] Line count is 7425.
[INFO] Hex File Valid!
```

Restart the device by powering off and on.

- After the restart, the firmware update will proceed.

7 HARDWARE and MECHANICAL SPECIFICATIONS

7.1 Electrical Interface Specifications

7.1.1 Power

ArNav devices work in between 4.75 and 32 volts. Current consumption is less than 300mA at 5V and less in higher voltages.

7.1.2 ArNav M2 I/O connector

The M2 device has two connectors. Main connector is 10 pin Fischer Ultimate Series **UR02W07 F010P BK1 E2AB**. Its mating connector is **UP01L07 M010S BK1 Z2ZB**. Secondary connector is 9 pin Fischer Ultimate Series **UR02W07 F009P BK1 E2AB** and it is mating connector is **UP01L07 M009S BK1 Z2ZB**. All ArNav M Series devices have at least one RS232 and one RS422 communication port. Also all devices have a timepulse sync signal from GNSS and one general purpose I/O pin. Depending of the device version additional RS232, CAN bus and two GPIO ports can be supported by a secondary connector. Pin description is given in Table 28 and Table 29.

Figure 12: ArNav M2 Main Connector Pin Positions, Front View

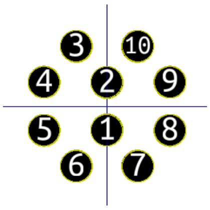


Figure 13: ArNav M2 Auxiliary Connector Pin Positions, Front View

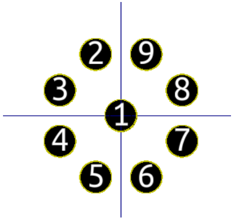


Table 28: ArNav M2 Main Connector Pin Description

Pin	Name	Description
1	Timepulse	Sync signal from Gps
2	Reserved	Should not be connected
3	RS232 TX 1	Main RS232 Transmit Line
4	RS232 RX 1	Main RS232 Receive Line
5	Ground	Signal and power ground
6	Power In	4.75 to 32V Power Input
7	RS422 A	RS422 Receive Positive Polarity, RX+
8	RS422 B	RS422 Receive Negative Polarity, RX-
9	RS422 Y	RS422 Transmit Positive Polarity, TX+
10	RS422 Z	RS422 Transmit Negative Polarity, TX-

Table 29: ArNav M2 Auxiliary Connector Pin Description

Pin	Name	Description
1	Reserved	Should not be connected
2	Reserved	Should not be connected
3	RS232 TX 2	Secondary RS232 Transmit Line
4	RS232 RX 2	Secondary RS232 Receive Line
5	Ground	Signal and power ground
6	Reserved (Power In/Out)	Should not be connected
7	Can H*	Not all devices support CAN bus
8	Can L*	Not all devices support CAN bus
9	Reserved	Should not be connected

7.1.3 ArNav S1 I/O connector

ArNav S1 device has one 16 pin male Harting Har-Flex connector (P/N 15 12 016 2601 000). Its mating connector is mezzanine female connector (P/N 15 21 016 2601 000) or Har-Flex female IDC cable (P/N 15 29 016 2501 000)
ArNavS1 devices have two RS232 and one RS422 communication port. Also all devices have a timepulse sync signal from GNSS and two configurable general purpose I/O pin. Depending of the device version CAN bus can be supported. Pin description is given in Table 30.

Figure 14: ArNav S1 Connector Pin Positions, Front View

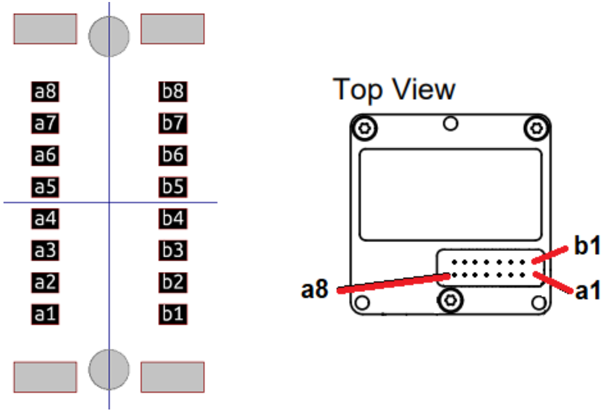


Table 30: ArNav S1 Connector Pin Description

Pin	Name	Description
a1	RS232 TX 1	Main RS232 Transmit Line
b1	Ground	Signal and power ground
a2	RS232 TX 2	Main RS232 Transmit Line
b2	Timepulse	Sync signal from Gps
a3	RS232 RX 1	Main RS232 Receive Line
b3	Reserved	Should not be connected
a4	RS232 RX 2	Main RS232 Receive Line
b4	Reserved	Should not be connected
a5	RS422 A	RS422 Receive Positive Polarity, RX+
b5	Power In	4.75 to 32V Power Input
a6	RS422 B	RS422 Receive Negative Polarity, RX-
b6	Ground	Signal and power ground
a7	RS422 Y	RS422 Transmit Positive Polarity, TX+
b7	Can H*	Not all devices support CAN bus
a8	RS422 Z	RS422 Transmit Negative Polarity, TX-
b8	Can L*	Not all devices support CAN bus

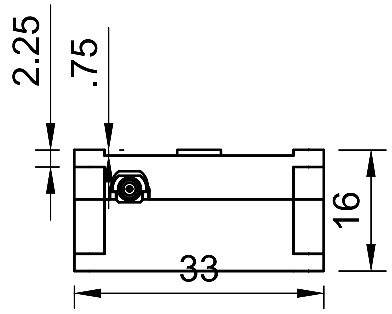
7.1.4 GNSS antenna connector

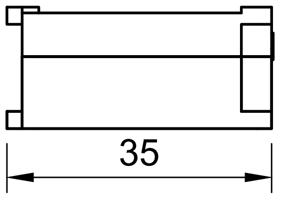
ArNav M2 has female SMA connector on the device. ArNav S1 has female MMCX connector on device. Both active and passive GNSS antennas are supported.

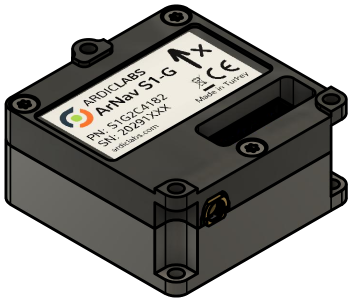
7.2 S1 and M2 Technical Drawings

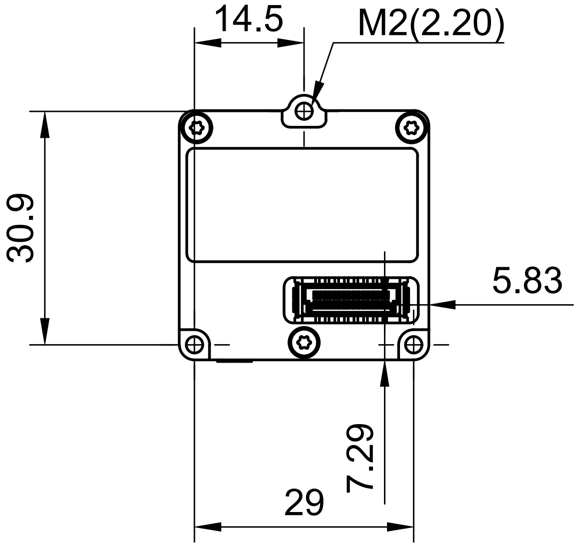
Outline Dimensions

ArNav S1





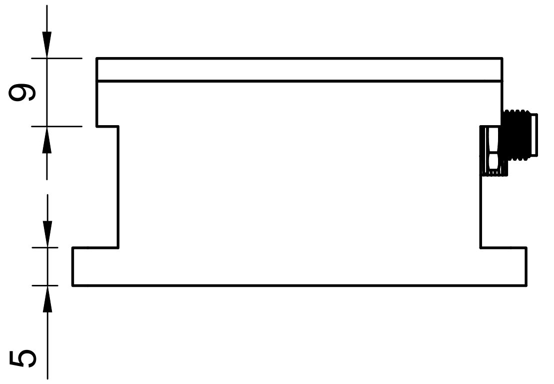


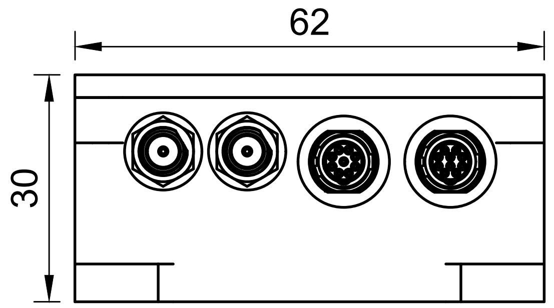


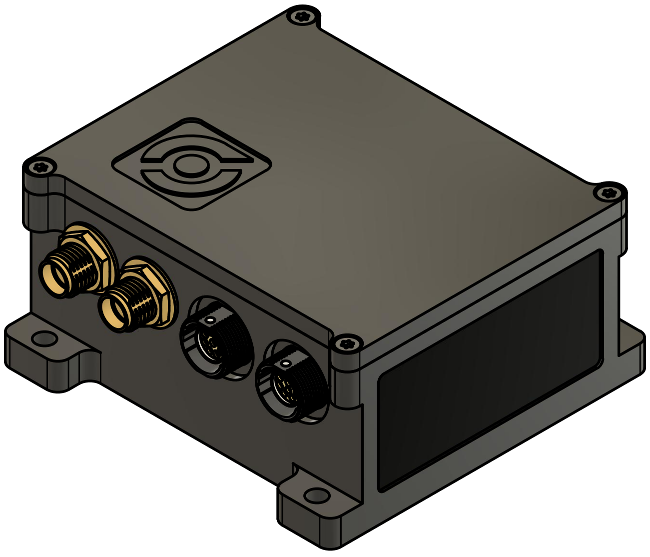
-Dimensions shown in millimeters
-Scale 1:1

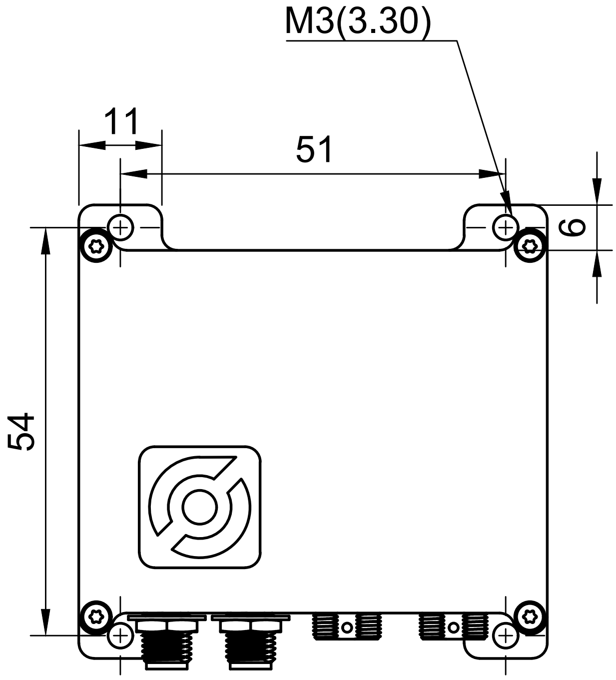
Outline Dimensions

ArNav M2









Dimensions shown in millimeters

Appendix A   Cyclic Redundancy Check in C

```
#include <stdint.h>

uint16_t Crc16_CCITT(int wLength, char *pData)
{
        int i;
        uint16_t wCrc = 0xffff;

        while (wLength--) {
                wCrc ^= *(unsigned char *)pData++ << 8;
                for (i = 0; i < 8; i++)
                wCrc = wCrc & 0x8000 ?  (wCrc << 1) ^ 0x1021 : wCrc << 1;
        }

        return wCrc & 0xffff;
}
```

Appendix B Cyclic Redundancy Check in C Sharp

```
static UInt16 Crc16_CCITT(int wLength, char[] pData)
{
        UInt32 wCrc = 0xffff;
        int i = 0;
        while (wLength-- != 0)
        {
                wCrc ˆ= (UInt32)(pData[i++] << 8);
                for (int k = 0; k < 8; k++)
                wCrc = (((wCrc & 0x8000) != 0) ? (wCrc << 1) ˆ 0x1021 : wCrc << 1);
        }

        return (UInt16)(wCrc & 0xffff);
}
```

Appendix C Ordering Guide

Table 31: System Product Number Structure

Interface		Reserved	IMU Specs		Reserved
X	X	X	X	X	X
05		X	43		X

Hexadecimal

Value	Interface
0x01	RS-232a
0x02	RS-232b
0x04	RS-422
0x08	TTL

Binary

Value	Accelerometer (g)		Gyroscope (°/s)	
	M Series	S Series	M Series	S Series
18	8	6	250	250
19	8	6	500	500
29	16	12	2000	2000
43	40	-	500	-

The hexadecimal values corresponding to the system's serial communication interfaces must be summed and assigned to the first two digits. Third digit is kept as reserved. Fourth and fifth digits represent the IMU specifications. The specifications for each value can be seen above.

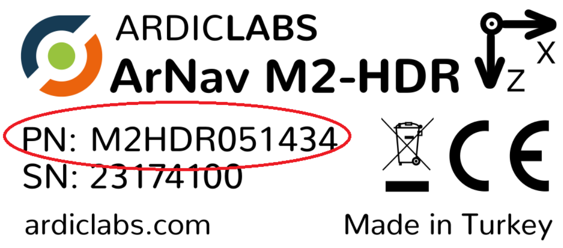


Figure 15: Product Number Example

M2	HDR	05	1	43	4
Product Family	Product	Interface	Reserved	IMU Specs	Reserved
M2 Series	HDR	1xRS232 and 1xRS422	Reserved	40g / 500°/s	Reserved

Appendix D Firmware Change Log

Table 32: ArNav System's Firmware and Feature Relation Table

Referance Number	Firmware Version
p1	20000 - ...

In this manual, specific features are denoted by reference numbers as outlined in Table 32. It's important to note that features labeled with these reference numbers are specific to the corresponding firmware versions.