Duro Inertial - User Guide

Supported Platforms

Platform	Duro Inertial
Firmware	≥ 2.1.21

Overview

Duro Inertial is a ruggedized version of Swift Navigation's Piksi® Multi dual-frequency Real Time Kinematics (RTK) GNSS receiver including Carnegie Robotics' SmoothPose™ sensor fusion algorithm, which combines GNSS and inertial measurements into an unified solution. The combination of GNSS and inertial measurements allows Duro Inertial to provide highly-accurate, continuous position solutions during brief GNSS outages and to deliver robust precision navigation solutions in harsh GNSS environments.

Prerequisites

This document describes the installation, configuration, and operation of features specific to Duro Inertial. Users should be familiar with the information contained in the Duro User Manual before following this guide.

Duro User Manual - https://www.swiftnav.com/latest/duro-user-manual

Contents

System Architecture

Typical system setup is shown in the diagram below. The product is able to combine real time GNSS observables from a base and a rover as well as motion sensed by the MEMS IMU in the product into one Fused RTK GNSS + INS position, velocity, and time solution.

Multi-frequency GNSS Antenna

Duro Inertial Configuration
(Lever arm offsets and vehicle body frame rotations)

GNSS Corrections Delivery System
(Optional but required for high-accuracy positioning)

Duro Inertial

GNSS Correction Source
(Base station, Skylark, or 3rd party correction service)

Radio Modem / Cell Modem

GNSS and RTK Engine
(Piksi Muti)

Smoothpose Loosely Coupled sensor Fusion

Platform Movement
(Acceleration and attitude rate)

Raw IMU Measurements
(BOSCH BMI160 MEMS IMU on Piksi Muti)

Duro Communication Interfaces (Serial, Uart Ethernet, etc)

DC Power

Loosely Coupled PVT Solution
Position, Velocity, time, & Attitude at rates up to 10 Hz

Installation

For proper Duro Inertial operation it is essential to mount both the Duro Inertial and the GNSS antenna securely and firmly to the vehicle body. During operation, the antenna and Duro Inertial must remain in the same position relative to each other (i.e., both must be mounted on the same frame).

GNSS Antenna Mounting

For the best signal reception, mount the GNSS antenna on a stable structure located away from other antennas and devices.

The GNSS antenna should be mounted completely externally. Do not place the GNSS antenna inside, or partially inside, of a housing or vehicle.

The GNSS antenna should have the best achievable sky view, in all directions, down to the horizon. Do not shield or occlude any portion of the antenna.

The GNSS antenna is sensitive to its environment. Since producing high-accuracy GNSS position solutions requires tracking carrier phase information from satellites, it is much more sensitive to obstructions than standard consumer GNSS receivers (like those found in smartphones).

All antenna offset measurements will occur from the phase center of the GNSS antenna.

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Duro Inertial Mounting

In order to properly detect motion, Duro Inertial must be securely and firmly mounted to the vehicle. Mounting Duro Inertial on the vehicle centerline is recommended.

To maximize sensor sensitivity, mounting Duro Inertial in an orientation orthogonal to the vehicle-body is recommended. This means that Duro Inertial should be mounted with all three axes forming angles in multiples of 90° (0°, 90°, 180°, 270°...), with respect to the primary direction of vehicle motion. For easier installation and setup, it is recommended to align the X-axis direction of the Duro Inertial with the primary direction of vehicle motion.

Duro Inertial must be rigidly mounted to the body of the vehicle. Any vibration which is not directly related to vehicular motion will degrade the quality of the inertial data. Installing Duro Inertial on a flexible vehicle rooftop, engine cover, or fender - where the mounting surface can flex and vibrate independently of the vehicle body - should be avoided. Similarly, placing the sensor on plush seating of a vehicle with the antenna on the rigid part of the vehicle will yield poor results.

Ensure that the Duro Inertial enclosure is on the same rigid body as the GNSS antenna. Some suspension systems may isolate the chassis from the cab and if the antenna moves when the Duro Inertial does not it will degrade results. When installing the device inside a vehicle, directly mounting it to the vehicle chassis is recommended. If installing the device externally, it is recommended to mount the device near the roof support structure, or on a rigid roof rack. Ideally, Duro Inertial should be mounted rigidly to the vehicle's inertial mass, directly above the center of rotation (i.e the pivot point).

A straightforward approach to installing Duro Inertial is to mount it on a rigid surface, located on the top of the vehicle, with the GNSS antenna attached to the receiver using included bracket. This approach is demonstrated in Figure 1. Mounting the GNSS antenna directly on the top of the receiver improves performance and makes setup easier. In this configuration, there is no need to measure the antenna lever arm - the default antenna offset settings can be used.

Figure 1: Duro Inertial sample mounting

If it is impractical to mount the entire Duro Inertial system on the top of a vehicle, mounting the Duro Inertial enclosure and GNSS antenna to the same rigid body, while minimizing the distance between them, is recommended. Ideally, the GNSS antenna should be mounted directly above Duro Inertial - with the antenna and enclosure both mounted on the vehicle centerline. On passenger vehicles, practical mount points for the Duro Inertial enclosure may include: the spare tire bay, the seat support rails, and the floor of the vehicle chassis.

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Antenna Offset

After installing the GNSS antenna and Duro Inertial on the vehicle, the antenna offset should be measured. The antenna offset consists of X, Y, and Z components which should be measured along Duro Inertial's X, Y, and Z axes (i.e. within the device frame). The "Device Frame" is the reference frame aligned with the markings on the Duro Inertial enclosure. These values will need to be provided to the device firmware settings during the configuration step.

On Duro Inertial, the device frame reference point is the intersection of the reference mark from the top of the enclosure and the bottom surface of Duro Inertial (see: Figure 2). The orientation of the device frame is shown in Figure 3. Note, the Z-axis is defined to be in the "down" direction.
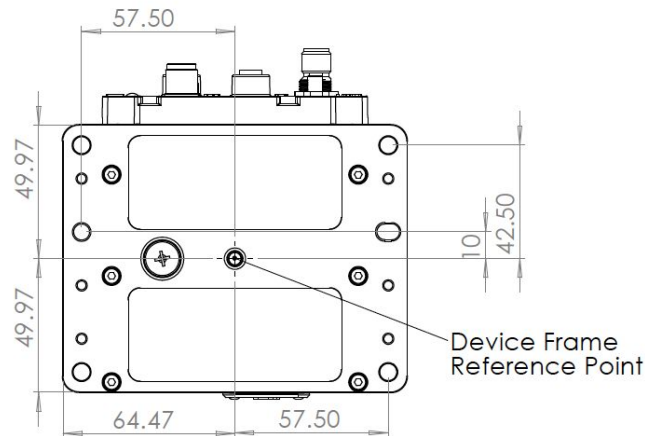
FIgure 2: Device Frame Reference Point (dimensions in millimeters)
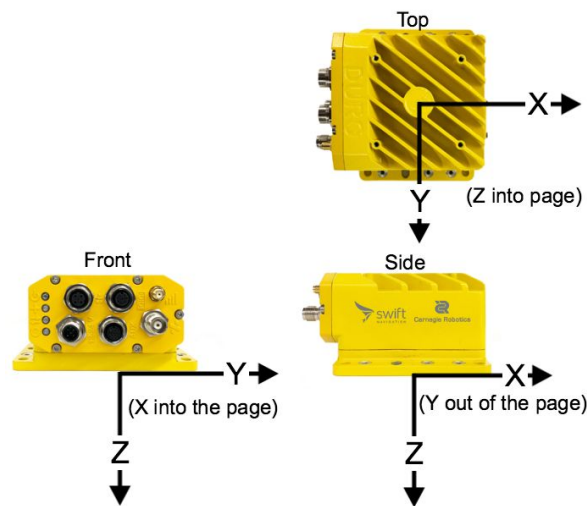
Figure 3: Device Frame Orientation

Distance value in the marked direction of the axis will have a positive sign. The value in the opposite direction will have a negative sign. Distances should be measured in meters, with 1-cm accuracy, from the Duro Inertial reference point to the phase center of the GNSS antenna.

The phase center of the GPS500 GNSS mini-survey antenna is located at the center of the antenna, 48 mm above the bottom of antenna mount (middle point between L1 and L2 phase centers).
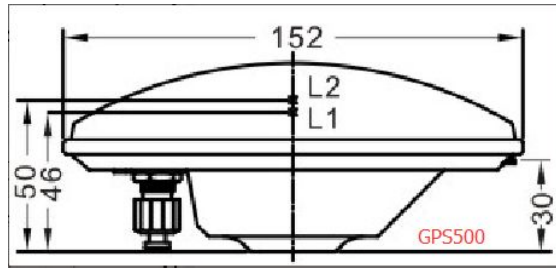
Figure 4: GPS500 mini-survey antenna phase center location.

Use the Duro Inertial Vehicle Profile Worksheet provided in Appendix C to write down antenna offset measurements taken on the vehicle for future reference.

Vehicle Frame Orientation

In addition to the antenna offset, the vehicle frame orientation should be measured. Entering proper orientation to the Duro Inertial firmware settings is essential for a correct navigation output.

To obtain yaw, pitch, and roll angles for the orthogonal mounting, refer to Appendix B - Duro Inertial Orientations, and use the values which match your installation. One way to think of the vehicle frame orientation is the rotations required to make the axis of the vehicle frame align with the axis marked on Duro.

Use the Duro Inertial Vehicle Profile Worksheet provided in Appendix C to record vehicle frame orientation values for future reference. The vehicle frame, and the pitch roll and yaw orientation directions, are defined according to the diagram below, where z is defined into the page.
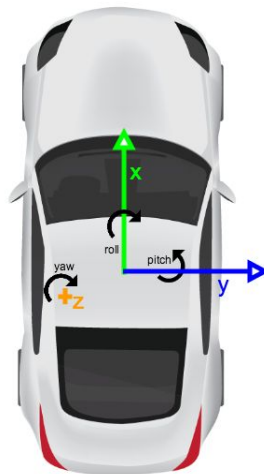

Figure 5: Vehicle Frame definition

Configuration

For proper operation, and the best performance, Duro Inertial firmware needs to be configured correctly. Duro Inertial has all applicable settings for Piksi Multi and Duro in addition to the Duro Inertial specific settings in the "ins" (inertial navigation system) settings grouping. Follow the instructions below to setup Duro Inertial firmware.

Firmware Version

Duro Inertial requires Piksi Multi firmware v2.1.21 or newer. The latest firmware can be downloaded from the Swift Navigation Support portal (https://support.swiftnav.com).

Default Configuration

By default, Duro Inertial is configured to be used with the Swift GNSS mini-survey antenna mounted directly to the Duro Inertial enclosure - using the included mounting bracket. However, Duro Inertial is shipped with IMU and INS outputs disabled by default. This is done to avoid outputting position solutions from a possibly incorrectly configured system.

In order to enable INS operation:
- Connect to Duro Inertial via Swift Console
- Select the *Settings* tab
- Locate the *INS* settings group
- Set *output_mode* to "Loosely Coupled"
- Swift Console will then offer to configure the settings for INS operation

In this configuration: *imu_rate* is set to 100 Hz, *acc_range* is set to 8 g, *gyro_range* is set to 125 deg/s, and *dr_duration_max* is set to 10 s.

Firmware Settings

There are a number of firmware settings which directly affect the behavior of Duro Inertial. These are detailed in the tables below. Device settings can be configured via Swift Console on the Settings tab or directly via SBP messages.

IMU Settings

IMU settings control range and output rate from inertial sensors.

Settings Group: imu				
Name	**Units**	**Accepted Values**	**Default Value**	**Description**
acc_range	g	2, 4, 8, 16	8	Acceleration sensor range.
gyro_range	deg/s	125, 250, 500, 1000, 2000	125	Angular rate sensor (gyroscope) range.
imu_rate	Hz	25, 50, 100, 200	100	IMU raw output data rate.
imu_raw_output	n/a	True, False	False	Enable/Disable IMU raw data output.

Notes
- Gyroscope and Accelerometer ranges (*acc_range*, *gyro_range*) should be adjusted for the dynamics of your application. In order to maintain the highest resolution of measurements, choose the smallest range which encompasses the dynamics of your application. However, keep in mind that your application may involve sudden, maximum dynamic changes which may not be typical or anticipated. These maximums should be used when selecting a scale for both accelerometer and gyroscope ranges.
- Duro Inertial does not use the magnetometer sensor and therefore the *mag_raw_output* and *mag_rate* parameters do not need to be set.
- In order to use inertial navigation, *imu_raw_output* must be enabled and *imu_rate* must be set to 100 Hz.

- Remember to click Save on Device button on the Swift Console Settings tab to store new values on the device.

INS Settings

INS settings control inertial navigation sub-system operation.

Settings Group: ins				
Name	**Units**	**Accepted Values**	**Default Value**	**Description**
antenna_offset_x	m		0	Distance along Duro Inertial X-axis from the reference point to the antenna phase center
antenna_offset_y	m		0	Distance along Duro Inertial Y-axis from the reference point to the antenna phase center
antenna_offset_z	m		-0.12674	Distance along Duro Inertial Z-axis from the reference point to the antenna phase center
dr_duration_max	s	0 ..	10	Sets the maximum duration for which the inertial system will dead reckon
output_mode		Disabled, Loosely Coupled, Debug	Disabled	Sets the operation mode of the inertial navigation system. Use Loosely Coupled mode for normal INS operation.
vehicle_frame_pitch	deg	-180 .. 180	0	Pitch angle representing rotation from vehicle frame to device frame. Rotations are performed extrinsically in the order roll, pitch, then yaw.
vehicle_frame_roll	deg	-180 .. 180	0	Roll angle representing rotation from vehicle frame to device frame. Rotations are performed extrinsically in the order roll, pitch, then yaw.
vehicle_frame_yaw	deg	-180 .. 180	0	Yaw angle representing rotation from vehicle frame to device frame. Rotations are performed extrinsically in the order roll, pitch, then yaw.
constrain_vehicle_sideslip	n/a	True, False	False	Enables or disables the non-holonomic constraint feature that allows inertial system to make assumptions about vehicle dynamics. This feature is not currently supported. This is an advanced setting and should only be enabled provided the vehicle frame Euler angles are measured precisely and are correct. It assumes a vehicle can have no velocity in the direction aligned with the vehicle "y" axis (i.e no sideslip). This is a reasonable assumption for passenger vehicles and many tractors.
odometry_noise_1 odometry_noise_2 odometry_noise_3 odometry_noise_4			0.28	Noise parameters for odometry sources. This is an advanced setting and is not currently supported.

Notes:
- Enter *antenna_offset_x/y/z* and *vehicle_frame_yaw/pitch/roll* as they were measured after installation. The worksheet in Appendix C is a useful tool for determining these values.

- *dr_duration_max* can be increased if low position accuracy is acceptable in DR mode
- Do not modify other parameters. They are used for development and testing only.
- Remember to click Save on Device button on the Swift Console Settings tab to store new values on the device.

Other Settings

All other Duro Inertial settings (like ports, protocols, rates, etc.) are the same as a standard Duro GNSS-only receiver. Please reference the Duro User Manual for details about configuring data ports, protocols, message rates, etc…

RTK Corrections

For the most precise and accurate position output, Duro Inertial should operate in RTK mode. Select and configure an RTK correction source in the same manner as a GNSS-only Duro. Refer to the Duro User Manual and support articles on the Swift Navigation Support Portal (support.swiftnav.com) for details.

Operation

With the INS system enabled, Duro Inertial will provide enhanced position output, including Dead Reckoning (DR) mode. Additionally, the contents of several messages will include status information about the INS.

Duro Inertial requires a valid GNSS solution to initialize the inertial subsystem. After the first valid GNSS solution, the INS is able to aid GNSS in precise positioning through challenging environments (like tree foliage and urban canyons) and to provide navigation solutions during brief GNSS outages (such as overpasses and short tunnels).

Since inertial sensors drift over time, resulting in decreased position accuracy, the DR mode operation is time-limited by the *dr_duration_max* setting (see settings in section above).

LED Indicators

Duro Inertial uses front panel LEDs to indicate when the INS is operational and the output position is computed using both GNSS and inertial subsystem. Purple lights for the POS LED indicate that INS is in use. Refer to the LED description table below for detailed information.
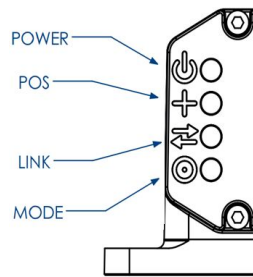
Figure 6: Duro Inertial LED indicators

LED Description			
LED Name	**Color**	**State**	**Description**
POWER	LED Off	Off	No power
	Green	Continuously on	Device receiving power
POS	LED Off	Off	No position, GNSS antenna not detected
	Orange	Slow blinking	No position, antenna detected, no satellite signals received, INS not initialized
	Orange	Fast blinking	No position, receiving satellite signals, INS not initialized
	Orange	Continuously on	Position valid, GNSS solution only, INS not used
	Purple	Fast blinking	Position valid, DR mode, no GNSS solution
	Purple	Continuously on	Position valid, combined GNSS and INS solution
	Purple Orange	Rapid blinking	Reserved (debug mode)
LINK	LED Off	Off	No incoming corrections, no Internet access
	Red	Blinking	Incoming corrections, no Internet access
	Red	Continuously On	Internet access available, no incoming corrections
	Red	On with intermittent flashing	Internet access available, incoming corrections
MODE	LED Off	Off	No RTK
	Blue	Blinking	Float RTK mode
	Blue	Continuously on	Fixed RTK mode

Note: after power up POS, LINK and MODE LEDs will blink white indicating boot up completed

Device Data Output

Duro Inertial is capable of providing output in Swift Binary Protocol (SBP) and industry standard NMEA 0183 protocol over UART and Ethernet ports. When INS is enabled, messages in both protocols will provide additional data described below.

SBP Messages

The subset of Swift Binary Protocol messages directly related to Duro Inertial operation are highlighted in the tables below. When using Duro Inertial, you may need to adjust the *enabled_sbp_messages* setting for the interfaces you use to communicate with the device. This setting is a comma separated list of message IDs (in decimal) that will be emitted on each interface. By default, the *enabled_sbp_messages* setting does not include any of the inertial-specific messages.

The following position mode values are reported in the "Fix Mode" field in the Status Flags (refer to the SBP protocol specification for more information):

0	No fix
1	Single Point Position (SPP)
2	Differential GNSS (DGNSS)
3	Float RTK
4	Fixed RTK
5	Dead Reckoning
6	SBAS

Additionally, the "Inertial Navigation Mode" field will contain INS status:

0	Message not produced by INS
1	Message produced by INS

Position Messages		
Message	**Message ID**	**Notes**
SBP_MSG_POS_LLH	522	
SBP_MSG_POS_LLH_COV	529	Message is not enabled by default.
SBP_MSG_POS_ECEF	521	Message is not enabled by default.
SBP_MSG_POS_ECEF_COV	532	Message is not enabled by default.

Velocity Messages		
Message	**Message ID**	**Notes**
SBP_MSG_VEL_NED	526	
SBP_MSG_VEL_NED_COV	530	Message is not enabled by default.
SBP_MSG_VEL_ECEF	525	Message is not enabled by default.

Message	Message ID	Notes
SBP_MSG_VEL_ECEF_COV	533	Message is not enabled by default.
SBP_MSG_VEL_BODY	531	Message is not enabled by default. Only produced when INS is enabled.

Orientation Messages		
Message	**Message ID**	**Notes**
SBP_MSG_ORIENT_QUAT	544	Message is not enabled by default. Only produced when INS is enabled.
SBP_MSG_ORIENT_EULER	545	Message is not enabled by default. Only produced when INS is enabled.
SBP_MSG_ANGULAR_RATE	546	Message is not enabled by default. Only produced when INS is enabled.

Status Messages		
Message	**Message ID**	**Notes**
SBP_MSG_INS_STATUS	65283	Message is not enabled by default. Only produced when INS is enabled.

Refer to the SBP protocol specification for message content details.

NMEA Messages

Following NMEA 0183 messages contain Dead Reckoning status information. NMEA messages do not contain orientation nor other INS specific information.

NMEA 0183 Messages	
Message	**Notes**
GGA	Quality Indicator: 0 - No fix 1 - Single Point Position (SPP) 2 - DGNSS or SBAS 4 - Fixed RTK 5 - Float RTK 6 - Dead Reckoning
GLL RMC VTG	Mode Indicator: N - No fix A - Autonomous fix D - DGNSS or SBAS E - Dead Reckoning (Estimated) F - Float RTK R - Fixed RTK

Known Issues

- Latency of Duro Inertial is dependent on the configuration of your device.
- Pin 17 Position Valid (PV) does not go high during Dead Reckoning
- NMEA will stop output after power cycle until a valid GNSS time is received
- Firmware upgrade with SmoothPose running will take 2-3x longer and data output during this time should be ignored. Please set *output_mode* in the *INS* settings to "Disabled" before performing firmware upgrades.
- Moving baseline heading is not currently utilized by SmoothPose

Appendix A - Identifying Duro Inertial

Duro Inertial receivers can be identified in following ways:

1. Duro Inertial has a product name and part number located on the bottom of the enclosure.
2. The "product_id" read-only setting reflects the product ID. This setting exists in the "system_info" group in the settings interface that can be accessed via the Swift Binary Protocol API or the Swift Console program.

Product	Duro® Inertial	Duro®
Part Number	00759-01 and 00759-02	00522-01
product_id	"Duro Inertial"	"Duro"

Appendix B - Duro Inertial Orientations

Use the pictures below to determine Duro Inertial orientation angles in your vehicle installation.

Angles are in degrees.

Yaw: 0 Pitch: 0 Roll: 0	Yaw: 90 Pitch: 0 Roll: 0	Yaw: 180 Pitch: 0 Roll: 0	Yaw: -90 Pitch: 0 Roll: 0
Yaw: 0 Pitch: 0 Roll: 180	Yaw: 90 Pitch: 0 Roll: 180	Yaw: 180 Pitch: 0 Roll: 180	Yaw: -90 Pitch: 0 Roll: 180
Yaw: 0 Pitch: 90 Roll: 0	Yaw: 0 Pitch: 90 Roll: -90	Yaw: 0 Pitch: 90 Roll: 180	Yaw: 0 Pitch: 90 Roll: 90

Yaw: 0 Pitch: -90 Roll: 180	Yaw: 0 Pitch: -90 Roll: -90	Yaw: 0 Pitch: -90 Roll: 0	Yaw: 0 Pitch: -90 Roll: 90
Yaw: -90 Pitch: 0 Roll: -90	Yaw: 0 Pitch: 0 Roll: -90	Yaw: 90 Pitch: 0 Roll: -90	Yaw: 0 Pitch: 180 Roll: 90
Yaw: 90 Pitch: 0 Roll: 90	Yaw: 180 Pitch: 0 Roll: 90	Yaw: -90 Pitch: 0 Roll: 90	Yaw: 0 Pitch: 0 Roll: 90

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Appendix C - Duro Inertial Installation Worksheet

Print and use this form to record Duro Inertial installation details and measurements. Antenna offset and vehicle frame rotation need to be entered to firmware settings for proper system operation.

General

Date	
Vehicle Name	
Duro Inertial S/N	

Antenna Offset (measured along X/Y/Z axis of Duro after installation)

X	Meters	
Y	Meters	
Z	Meters	

Vehicle Frame Rotation

Yaw (Z)	Degrees	
Pitch (Y)	Degrees	
Roll (X)	Degrees	

Appendix D - Device and Vehicle Frames

The three Euler-angle settings for configuring the Device frame orientation with respect to the vehicle frame orientation represent three extrinsic rotations in the order roll, pitch, and yaw. For example, a rotation matrix that can be used to rotate a vector from the device frame (i.e a velocity in the Duro Inertial frame X-direction) to the Vehicle Frame, can be represented as follows:

$$v_{vehicle} = R^{Device}_{Vehicle} * v_{device}$$

$$
\begin{bmatrix} v_{x-vehicle} \\ v_{y-vehicle} \\ v_{z-vehicle} \end{bmatrix} = \begin{bmatrix} \cos{(yaw)} & -\sin{(yaw)} & 0 \\ \sin{(yaw)} & \cos{(yaw)} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos{(pitch)} & 0 & \sin{(pitch)} \\ 0 & 1 & 0 \\ -\sin{(pitch)} & 0 & \cos{(pitch)} \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos{(roll)} & -\sin{(roll)} \\ 0 & \sin{(roll)} & \cos{(roll)} \end{bmatrix} * \begin{bmatrix} v_{x-device} \\ v_{y-device} \\ v_{z-device} \end{bmatrix}
$$

Extrinsic rotations are defined as rotations about the body where the body does not move.

Similarly, the Quaternion and Euler angle output from the device describe the orientation of the Vehicle Body Frame with respect to the Navigation frame in real time. The euler rotations should applied intrinsically in the order yaw, pitch, and roll in order to rotate the from a frame aligned with the local-level NED frame to the vehicle body frame. Mathematically, it can be shown that this description of the real time Euler angles is equivalent to an Extrinsic rotation in the order roll, pitch, yaw to rotate the vehicle frame into the local level NED frame. The equations below can be used to relate the Euler angles reported in MSG_ORIENT_EULER, to the Body velocities reported in MSG_VEL_BODY, to the Navigation velocities reported in MSG_VEL_NED.   The vehicle body frame is defined according to Figure 5.

$$v_{navigation} = R^{Vehicle}_{Nav} * v_{vehicle\ body}$$

$$
\begin{bmatrix} v_{north} \\ v_{east} \\ v_{down} \end{bmatrix} = \begin{bmatrix} \cos{(yaw)} & -\sin{(yaw)} & 0 \\ \sin{(yaw)} & \cos{(yaw)} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos{(pitch)} & 0 & \sin{(pitch)} \\ 0 & 1 & 0 \\ -\sin{(pitch)} & 0 & \cos{(pitch)} \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos{(roll)} & -\sin{(roll)} \\ 0 & \sin{(roll)} & \cos{(roll)} \end{bmatrix} * \begin{bmatrix} v_{x-vehicle-body} \\ v_{y-vehicle-body} \\ v_{z-vehicle-body} \end{bmatrix}
$$

Glossary

Term	Description
Antenna Offset	Three-dimensional distance between Duro Inertial and GNSS Antenna
Device Frame	The reference frame aligned with the XYZ axis markings on Duro Inertial
DR	Dead Reckoning
Dead Reckoning	Position computation method where the current position is computed based on a prior known position and an estimated movement
Firmware	Embedded software running on electronic device

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Fix	Valid position
DGPS, DGNSS	Differential GPS or GNSS
GNSS	Global Navigation Satellite System mainly including GPS, GLONASS, BeiDou (BDS), and Galileo satellite systems
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
Lever Arm	Three-dimensional distance between Duro Inertial reference point and GNSS antenna phase center
Loosely Coupled	Navigation technique that takes GNSS position data and combines it with inertial sensor measurements for a unified output
Phase Center	Point inside the GNSS antenna from which position is calculated
Piksi Multi	Swift Navigation RTK GNSS receiver module included in Duro Inertial
RTK	Real Time Kinematic
SBAS	Satellite Based Augmentation System
SBP	Swift Binary Protocol - Swift Navigation's proprietary protocol
SPP	Single Point Position
Swift Console	Graphic User Interface (GUI) program providing visual representation of what's happening inside Swift Navigation's Piksi Multi, Duro, and Duro Inertial GNSS receivers. Console displays information and allows to adjust the settings on the hardware. Available for Windows, macOS and Linux.
Tracking	Continuously receiving signals from GNSS satellites
Vehicle Frame	The reference frame aligned with the XYZ axis of the vehicle. X-axis is usually facing forward, Y to the right and Z down.

Additional References

Name / Link	Notes
Swift Binary Protocol	The fundamental API and communication interface of Swift receivers is SBP.
Swift Console	The Swift Console has helpful desktop software for evaluation and configuration of the receiver.
Duro User Guide & Duro Specifications	The features of the Duro Inertial Enclosure (dimensions, drawings, connectors, interfaces) are shared with the Duro and are documented in the Duro User guide.
Duro Troubleshooting Guide	