C. Radial Velocity Correction

The motion of a ship or airborne platform induces a radial velocity error. IRIS corrects for this error by accounting for the platform motion. Ship motion measurements are collected from the antenna controller and the radial velocity correction is optionally applied to the ingest files so that all subsequent products and the real time display are corrected. Note that the radial velocity correction and all of the platform motion parameters are archived as part of the extended ray header.

In this appendix:

C.1 Ship Motion Parameters and Coordinate Transformations

For systems with the SIGMET RCP02, the *RCP02 User's Manual* contains a full theoretical derivation of the stabilization. The basic variables of the ship motion sensing are defined below:

Symbol	**Definition**
HEAD	Heading measured CW from true north
θ	$HEAD - \pi/2$
$\dot{\theta}$	Rate of change of heading
P	Pitch measured relative to horizo**n** + for bow down
$\dot{P}$	Rate of change of pitch
R	Roll measured relative to the horizon + for port side down
$\dot{R}$	Rate of change of roll
u	Eastward velocity
v	Northward velocity
W	Upward velocity

Given a vector x in earth coordinates and the corresponding vector x' in ship coordinates,

$$\boldsymbol{x'} = \boldsymbol{A}\,\boldsymbol{x} \quad \text{and} \quad \boldsymbol{x} = \boldsymbol{A}^{-1}\,\boldsymbol{x'}$$

where the transformation matrices are:

$$\boldsymbol{A} = \begin{vmatrix} \cos P \cos\theta & -\cos P \sin\theta & -\sin P \\ \cos R \sin\theta - \sin R \sin P \cos\theta & \cos R \cos\theta + \sin R \sin P \sin\theta & -\sin R \cos P \\ \sin R \sin\theta + \cos R \sin P \cos\theta & \sin R \cos\theta - \cos R \sin P \sin\theta & \cos R \cos P \end{vmatrix}$$

$$\boldsymbol{A}^{-1} = \begin{vmatrix} \cos P \cos\theta & \cos R \sin\theta - \sin R \sin P \cos\theta & \sin R \sin\theta + \cos R \sin P \cos\theta \\ -\cos P \sin\theta & \cos R \cos\theta + \sin R \sin P \sin\theta & \sin R \cos\theta - \cos R \sin P \sin\theta \\ -\sin P & -\sin R \cos P & \cos R \cos P \end{vmatrix}$$

Note that $\boldsymbol{A}^{-1}$ is the transpose of A.

C.2 Radial Velocity Correction

The scalar radial velocity of the scatterers V_R can be expressed as:

$$V_R = V_{R\ meas} - V_{R\ ship}$$

where V_R *meas* is the Doppler velocity measured by the signal processor and $V_{R\ ship}$ is the radial velocity correction for ship motion. The radial velocity correction is found by taking the dot product of the antenna vector x in earth coordinates with the velocity of the antenna in earth coordinates $\dot{y}_A$, as follows:

$$V_{Rship} = \boldsymbol{x} \cdot \dot{\boldsymbol{y}}_A$$

The antenna vector is a unit vector pointing in the direction of the antenna which depends on the true (earth relative) azimuth and elevation of the antenna, as follows:

$$\boldsymbol{x} = \begin{vmatrix} \sin AZ \quad \cos EL \\ \cos AZ \quad \cos EL \\ \sin EL \end{vmatrix}$$

AZ and EL are earth relative

These are known from the antenna controller. Thus, the problem is to determine the $\dot{y}_A$ — the velocity of the antenna.

The velocity correction used in IRIS allows for two different types of ship motion sensing:

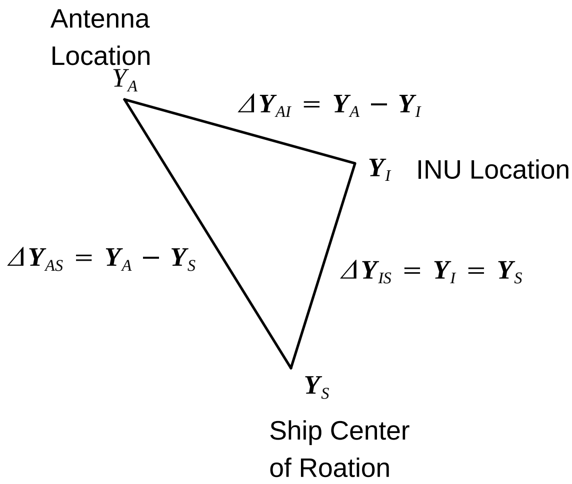
Inertial Navigation Unit (INU) The INU is typically located close to the antenna. The INU reports pitch, roll and heading, rates of change of these variables, as well as the east, north and vertical motion (*u*, v, w). In this case, the INU is used as the ship reference point.

Gyro System with GPS The gyros report pitch, roll and heading as well as rates of change of these variables. Mean translational motion of the center of the ship (u, v w) is obtained from a GPS or other navigational system. In this case the ship center of rotation is used as the ship reference point.

We shall refer to these two cases as the INU Case and the Gyro Case.

In either case, the interface to these devices is the RCP antenna control unit. All of the orientation and navigation information is passed to IRIS via the serial line connection to the antenna controller.

Figure C–1: Vectors used for Velocity Correction In Earth Coordinates



In general, the INU is not located at either the ship center of rotation or the antenna. The location vectors are shown in Figure C–1 in earth coordinates. The position vector of the antenna in earth coordinates can be expressed as:

$$\mathbf{y}_A = \mathbf{y}_I + (\mathbf{y}_A - \mathbf{y}_I) \qquad \text{INU Case}$$

$$\mathbf{y}_A = \mathbf{y}_S + (\mathbf{y}_A - \mathbf{y}_S) \qquad \text{Gyro Case}$$

so that,

$$\mathbf{y}_A = \mathbf{y}_I + \Delta\mathbf{y}_{AI} \qquad \text{INU Case}$$

$$\mathbf{y}_A = \mathbf{y}_S + \Delta\mathbf{y}_{AS} \qquad \text{Gyro Case}$$

where,

$$\Delta\mathbf{y}_{AI} = \mathbf{y}_{A} - \mathbf{y}_{I} \quad \text{and} \quad \Delta\mathbf{y}_{AS} = \mathbf{y}_{A} - \mathbf{y}_{S}$$

Expressing the Δ vectors in terms of the ship relative coordinates yields:

$$\mathbf{y}_A = \mathbf{y}_I + \mathbf{A}^{-1}\Delta\mathbf{y}'_{AI} \qquad \text{INU Case}$$

$$\mathbf{y}_A = \mathbf{y}_S + \mathbf{A}^{-1}\Delta\mathbf{y}'_{AS} \qquad \text{Gyro Case}$$

Differentiating these two expressions yields the final expressions for the antenna velocity:

$$\dot{\mathbf{y}}_A = \dot{\mathbf{y}}_I + \dot{\mathbf{A}}^{-1}\Delta\mathbf{y}'_{AI} \qquad \text{INU Case}$$

$$\dot{\mathbf{y}}_A = \dot{\mathbf{y}}_S + \dot{\mathbf{A}}^{-1}\Delta\mathbf{y}'_{AS} \qquad \text{Gyro Case}$$

Note that since the INU, antenna and ship center coordinates are not changing relative to the ship coordinates,

$$\Delta\dot{\mathbf{y}}'_{AS} = \Delta\dot{\mathbf{y}}'_{AI} = 0\,.$$

The components of the matrix $\dot{\boldsymbol{A}}^{-1}$ are as follows:

$$\dot{\boldsymbol{A}}^{-1} = \begin{vmatrix} \dot{A}_{11}^{-1} & \dot{A}_{12}^{-1} & \dot{A}_{13}^{-1} \\ \dot{A}_{21}^{-1} & \dot{A}_{22}^{-1} & \dot{A}_{23}^{-1} \\ \dot{A}_{31}^{-1} & \dot{A}_{32}^{-1} & \dot{A}_{33}^{-1} \end{vmatrix}$$

where:

$$\dot{A}_{11}^{-1} = -\dot{P}\ \sin P\ \cos\theta - \dot{\theta}\ \cos P\ \sin\theta$$

$$\dot{A}_{21}^{-1} = +\dot{P}\ \sin P\ \sin\theta - \dot{\theta}\ \cos P\ \cos\theta$$

$$\dot{A}_{31}^{-1} = -\dot{P}\ \cos P$$

$$\dot{A}_{12}^{-1} = -\dot{R}\ \sin R\ \sin\theta + \dot{\theta}\ \cos R\ \cos\theta - \dot{R}\ \cos R\ \sin P\ \cos\theta - \dot{P}\ \sin R\ \cos P\ \cos\theta + \dot{\theta}\ \sin R\ \sin P\ \sin\theta$$

$$\dot{A}_{22}^{-1} = -\dot{R}\ \sin R\ \cos\theta - \dot{\theta}\ \cos R\ \sin\theta + \dot{R}\ \cos R\ \sin P\ \sin\theta + \dot{P}\ \sin R\ \cos P\ \sin\theta + \dot{\theta}\ \sin R\ \sin P\ \cos\theta$$

$$\dot{A}_{32}^{-1} = -\dot{R}\ \cos R\ \cos P + \dot{P}\ \sin R\ \sin P$$

$$\dot{A}_{13}^{-1} = +\dot{R}\ \cos R\ \sin\theta + \dot{\theta}\ \sin R\ \cos\theta - \dot{R}\ \sin R\ \sin P\ \cos\theta + \dot{P}\ \cos R\ \cos P\ \cos\theta - \dot{\theta}\ \cos R\ \sin P\ \sin\theta$$

$$\dot{A}_{23}^{-1} = +\dot{R}\ \cos R\ \cos\theta - \dot{\theta}\ \sin R\ \sin\theta + \dot{R}\ \sin R\ \sin P\ \sin\theta - \dot{P}\ \cos R\ \cos P\ \sin\theta - \dot{\theta}\ \cos R\ \sin P\ \cos\theta$$

$$\dot{A}_{33}^{-1} = -\dot{R}\ \sin R\ \cos P - \dot{P}\ \cos R\ \sin P$$

These equations show that the motion of the antenna can be expressed as a translational motion of a reference point (either at the INU or at the ship center of rotation), plus a rotational motion about a moment arm from the reference point to the antenna.

The translational motion of the reference point is:

$$\dot{\boldsymbol{y}}_{\boldsymbol{I}} = \begin{vmatrix} u \\ v \\ w \end{vmatrix}$$ as sensed by the INU for the INU case

$$\dot{\boldsymbol{y}}_{\boldsymbol{S}} = \begin{vmatrix} u \\ v \\ w \end{vmatrix}$$ as sensed by the GPS for the Gyro Case

As a special case, if the INU and antenna are located at precisely the same position, then,

$\Delta \boldsymbol{y}'_{\boldsymbol{AI}} = 0$ so that $\dot{\boldsymbol{y}}_{\boldsymbol{A}} = \dot{\boldsymbol{y}}_{\boldsymbol{I}}$ INU Case

In this case, the antenna velocity is equal to the INU velocity since the moment arm is zero length.

C.3 Configuration

Measure and Input the Moment Arm Vector Components. The moment arm vector components are input via the **setup** utility. These are, for the two cases:

INU Case $\Delta y'_{AI!}$:

$\Delta y'_{AI1}$	Antenna distance forward of INU in deck plane.
$\Delta y'_{AI2}$	Antenna distance to port of INU in deck plane.
$\Delta y'_{AI3}$	Antenna distance upward from INU normal to deck plane.

Gyro Case $\Delta y'_{AS}$:

$\Delta y'_{AS1}$	Antenna distance forward of ship center in deck plane.
$\Delta y'_{AS2}$	Antenna distance to port of center line in deck plane.
$\Delta y'_{AS3}$	Antenna distance upward from ship center normal to deck plane.

The three measurements should be made to the antenna feed horn. The signs of the components must be strictly observed The units are meters. Note that the questions in **setup** refer to the INU case. If you have the Gyro Case, enter the corresponding moment arms relative to the ship center of rotation.

Setup has an additional question regarding the height offset of the INU. This is a fixed number which is added to the height reported by the INU. Since most INU's accurately report the height, this number should be set to zero. The value of this number does not effect the velocity correction.

- Specify the proper antenna format in **setup** RCP section.
- Specify the Extended Ray Header in **setup**, ingest section.
- If you have a SIGMET RCP02, configure as described in the *RCP02 User's Manual*.
- Use the TASK Configuration menu to turn on and off the velocity correction for each TASK.

C.4 Testing

SIGMET provides several programs for testing the velocity correction feature.

C.4.1 The Antenna Utility

The primary utility is the **antenna** utility as described in the *IRIS Utilities Manual*. This utility displays all of the navigation information that is reported back from the antenna controller as well as the velocity of the antenna $\Delta\dot{y}_A$ and the velocity correction. The Antenna utility should be used to verify the following:

- The signs of all angles (pitch, roll, heading).
- The signs of angular velocities (pitch, roll, heading).
- The signs of the translational velocities (u, v, w).
- That the velocity corrections are reasonable and free of glitches caused by unreliable input data.

C.4.2 The Rays Utility

The **rays** utility allows ingest data to be examined. In addition, because RAW products can be brought back from archive to create regenerated ingest files, the data recording can be checked. Using the **rays** utility values, the velocity correction algorithm can be verified from an independent calculation.

C.5 In Situ Testing Suggestions

The final testing must be done at sea. This is an uncontrolled environment for testing, however, there is a useful total system test of the velocity correction — fixed ground targets should have zero corrected velocity as observed from the moving platform. Do not use buoys with radar reflectors. They are excellent targets, but they are generally not stationary.

This can be tested by cruising offshore of a coast at ~10 km and observing fixed ground targets while collecting IRIS data. You may want to use a sector scan for this at low elevation. You should verify the following:

- The real time color display should show ground targets at zero velocity.
- The Rays utility should show targets at zero velocity.
- PPI velocity products with a fine resolution velocity scale can be constructed to verify the velocity correction.

If the corrected velocity of ground targets is not zero, you must isolate the problem. If the antenna is properly stabilized, it is likely that both the INU (or Gyro system) and the antenna controller are functioning properly. Therefore, the error is most likely due to alignment:

- The INU or Gyro system vertical and the antenna vertical must be co-aligned.
- The INU or Gyro system azimuths must be co-aligned.
- The moment arms must be properly measured.

The INU or Gyro/Antenna alignment can be checked with the sun tracking feature of the Antenna utility. The moment arm measurement can be checked dynamically as described below.

C.5.1 Dynamic Adjustment of Moment Arms

Measuring moment arms or extracting them from the ship's drawing may be difficult to do. The athwartship component of the moment arm is usually the easiest measure and, in most cases, the antenna is centered across the ship. This leaves the vertical and the for/aft moments. By observing ground targets in special ship/antenna configurations, it is possible to check these moments dynamically.

The vertical component of the moment arm can be isolated by scanning over the beam of the ship while looking at on-shore clutter targets. In this case, the velocity correction is dominated by the roll of the ship and the vertical moment arm. The athwartship position error of the antenna moment arm has the same effect. In this configuration, the vertical moment arm can be adjusted in Antsetup until the observed velocity of ground targets is zero. The ship must be rolling during this test.

After this is done, the antenna can be pointed fore or aft to observe clutter targets. The fore/aft component of the moment arm can be adjusted to remove any remaining velocity error. The ship must be pitching during this test.

C.6 Summary of Velocity Correction Algorithm: INU Example

1. $V_R = V_R - V_R \ ship$

2. $V_{Rship} = \mathbf{x} \cdot \dot{\mathbf{y}}\mathbf{A}$

3. $\dot{\mathbf{y}}_{\mathbf{A}} = \dot{\mathbf{y}}_{\mathbf{I}} + \dot{\mathbf{A}}^{-1} \Delta \ \mathbf{y}'_{\mathbf{AI}}$

4. $\dot{\mathbf{y}}_I = \begin{vmatrix} SpeedEast \\ SpeedNorth \\ SpeedUp \end{vmatrix}$ as measured by the INU.

5. $\Delta \mathbf{y}_{\mathbf{AI}} = antenna \ \ position \begin{vmatrix} forward \\ port \\ over \end{vmatrix}$ the INU position

6. $\dot{\mathbf{A}}^{-1} = \begin{vmatrix} \dot{A}_{11}^{-1} & \dot{A}_{12}^{-1} & \dot{A}_{13}^{-1} \\ \dot{A}_{21}^{-1} & \dot{A}_{22}^{-1} & \dot{A}_{23}^{-1} \\ \dot{A}_{31}^{-1} & \dot{A}_{32}^{-1} & \dot{A}_{33}^{-1} \end{vmatrix}$

$$\dot{A}_{11}^{-1} = -\dot{P} \ \sin P \ \cos\theta - \dot{\theta} \ \cos P \ \sin\theta$$

$$\dot{A}_{21}^{-1} = +\dot{P} \ \sin P \ \sin\theta - \dot{\theta} \ \cos P \ \cos\theta$$

$$\dot{A}_{31}^{-1} = -\dot{P} \ \cos P$$

$$\dot{A}_{12}^{-1} = -\dot{R} \ \sin R \ \sin\theta + \dot{\theta} \ \cos R \ \cos\theta - \dot{R} \ \cos R \ \sin P \ \cos\theta - \dot{P} \ \sin R \ \cos P \ \cos\theta + \dot{\theta} \ \sin R \ \sin P \ \sin\theta$$

$$\dot{A}_{22}^{-1} = -\dot{R} \ \sin R \ \cos\theta - \dot{\theta} \ \cos R \ \sin\theta + \dot{R} \ \cos R \ \sin P \ \sin\theta + \dot{P} \ \sin R \ \cos P \ \sin\theta + \dot{\theta} \ \sin R \ \sin P \ \cos\theta$$

$$\dot{A}_{32}^{-1} = -\dot{R} \ \cos R \ \cos P + \dot{P} \ \sin R \ \sin P$$

$$\dot{A}_{13}^{-1} = +\dot{R} \ \cos R \ \sin\theta + \dot{\theta} \ \sin R \ \cos\theta - \dot{R} \ \sin R \ \sin P \ \cos\theta + \dot{P} \ \cos R \ \cos P \ \cos\theta - \dot{\theta} \ \cos R \ \sin P \ \sin\theta$$

$$\dot{A}_{23}^{-1} = +\dot{R} \ \cos R \ \cos\theta - \dot{\theta} \ \sin R \ \sin\theta + \dot{R} \ \sin R \ \sin P \ \sin\theta - \dot{P} \ \cos R \ \cos P \ \sin\theta - \dot{\theta} \ \cos R \ \sin P \ \cos\theta$$

$$\dot{A}_{33}^{-1} = -\dot{R} \ \sin R \ \cos P - \dot{P} \ \cos R \ \sin P$$

Definition of terms in matrix A^{-1}

HEAD	Heading measured CW from true north
θ	$HEAD - \pi/2$
$\dot{\theta}$	Rate of change of heading
P	**P**itch measured relative to horizon + for bow down
$\dot{P}$	Rate of change of pitch
R	Roll measured relative to the horizon + for port side down
$\dot{R}$	Rate of change of roll