RSI Technical Note 046

RSI Inclinometers

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Change History

1. 2018-12-06, RGL and JMM, Original version based on JMM document.
2. 2019-02-07, JMM, Updated recommended torque and other minor edits.

1 Background

The purpose of this document is to clarify the functionality of the inclinometer within RSI's standard instruments. It explains the coordinate system used by RSI, the interpretation of the signals produced by the inclinometer, what parameters must be entered into a configuration file to collect data from the inclinometers, and how to test if these parameters are correct.

- Section 2 describes the ADIS-16209 inclinometer used in RSI instruments.
- Section 3 describes the orientation of the inclinometer within RSI instruments.
- Section 4 presents a simple bench test of the inclinometer and how you can conduct your own test.
- Section 5 discusses firmware and hardware issue with the inclinometer.

Those wishing to only test their inclinometer should go directly to section 4.

AD Name	RSI Name	Symbol	`id`
`XINCL_OUT`	`Incl_X`	θ_X	41
`YINCL_OUT`	`Incl_Y`	θ_Y	40
`TEMP_OUT`	`Incl_T`	θ_T	42

Table 1: Three of the signals that are produced by the ADIS-16209 inclinometer and read by RSI instruments. Column 1 – the names used by the manufacturer (Analog Devices). Column 2 – the names used by RSI. Column 3 – the symbols associated with the signals. Column 4 – The channel identification numbers (`id`) used by RSI. θ_T is the internally measured temperature of the inclinometer.

2 The ADIS Inclinometer

The inclinometer in RSI instruments is the model ADIS-16209CCCZ two-axis inclinometer manufactured by Analog Devices, Inc. It is located on the power-supply board (P050) manufactured by RSI (Figure 4). The inclinometer is configured and managed by a CPLD (Complex Programmable Logic Device) manufactured by Xilinx, Inc. Upon the initial application of power to the power-supply board, the CPLD configures the inclinometer to sample at a rate of $481.9\,\mathrm{s}^{-1}$ and to apply a running average of 256 samples to its internal data streams. The running average spans 0.53 s. The inclinometer provides data for several signals, but RSI instruments only read the signals `Incl_X`, `Incl_Y`, and `Incl_T` (Table 1). The CPLD continually extracts every 6^{th} ($\sim 80\,\mathrm{s}^{-1}$) sample of these signals, and keeps the latest triplet of samples ready for transfer to the data collection system.

2.1 Signals Measured

Like all inclinometers, the ADIS uses two internal accelerometers, a_X and a_Y, to detect an inclination with respect to the local horizontal plane in an earth frame. The earth frame is defined by the direction of the gravity vector $\mathbf{g} = -g[0,\,0,\,1]^T$ where the three elements in the square braces are the vector components along the X_E-, Y_E- and Z_E-axes of the earth frame. Z_E is directed positive upward, $g = 9.81\,\mathrm{m\,s^{-2}}$ is the magnitude of the gravitation acceleration, and X_E and Y_E are mutually orthogonal, and in the horizontal plane, but with no particular geographic orientation. Inertial accelerations cannot be distinguished from gravitation, according to the theory of General Relativity. This means that the acceleration vector, $\mathbf{a}$, obtained with any accelerometer is

$$\mathbf{a} = -\mathbf{g} + \ddot{\mathbf{x}} \tag{1}$$

where $\ddot{\mathbf{x}}$ is the vector of inertial acceleration. It is usually assumed that high-frequency accelerations are inertial, whereas very low-frequency signals are induced by gravity. Thus, a low-pass filtered acceleration signal is interpreted as an inclination out of the horizontal plane, but this is not unconditionally true [1].

[1] For example, if an accelerometer is placed on a level rotating table, it will experience a constant centripetal acceleration, which is interpreted as an inclination.

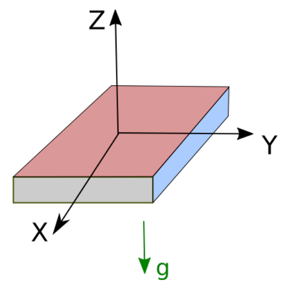

Figure 1: The coordinate system of an accelerometer/inclinometer when it is resting in the horizontal plane. There is zero acceleration in the X- and Y-directions and both directions are orthogonal to the vector of gravity (green).

To describe the signals produced by the inclinometer, we use upper case X, Y, and Z to identify the coordinate frame of the inclinometer. Three different orientations are presented below.

2.1.1 The Level Plane

Imagine that X and Y are in a level plane and that Z is directed upwards and parallel to the local gravity vector (Figure 1). Both the X- and the Y-accelerometers will report zero acceleration (i.e. $a_X = a_Y = 0$). Rotating the accelerometer around the Z-axis, will not induce any change in the accelerometer signals. If the inclinometer had a third axis that was sensitive to accelerations in the Z (up) direction, the measured signal would be $a_Z = +9.81\,\mathrm{m\,s^{-2}}$ (but this is not the case for the dual axis ADIS accelerometer).

2.1.2 Rotation around the X- *or* Y-axis

If we now rotate the accelerometer around either (i) the Y-axis (Figure 2, left side), or (ii) the X-axis (right side), then the output reported by the accelerometer will change. These acceleration signals are related to the angles of rotation θ_X and θ_Y shown in Figure 2 by

$$\begin{aligned} a_Y &= g \sin \theta_X \\ a_X &= -g \sin \theta_Y \ . \end{aligned} \tag{2}$$

Thus, the angles of rotation of the inclinometer in this example, are

$$\begin{aligned} \theta_X &= \sin^{-1}\left(\frac{a_Y}{g}\right) \\ \theta_Y &= \sin^{-1}\left(\frac{-a_X}{g}\right) \quad . \end{aligned} \tag{3}$$

The signals reported by the inclinometer are

$$\texttt{Incl\_X} = \theta_X \quad \text{and} \quad \texttt{Incl\_Y} = \theta_Y \tag{4}$$

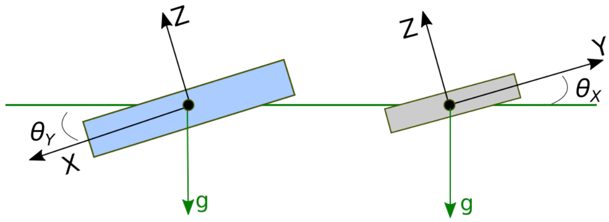

Figure 2: Left: Positive rotation around a horizontal Y-axis. Right: Positive rotation around a horizontal X-axis. In both figures, the third axis is coming out of the page (towards you) and the green line represents the horizontal plane.

in units of degrees (Table 1). The computation implied by eq. (3) is done internally by the inclinometer. Whether a rotation around an axis is positive or negative is determined by the right-hand rule for rotation (Figure 3). The axis of interest is aligned with, and directed by, the thumb of your right hand. Your slightly curled fingers point in the positive direction of rotation.

If the Z-axis is not aligned with the gravity vector (e.g. Figure 2), a subsequent rotation about the Z axis *does* change the reports from a_X or a_Y. In fact, an orientation similar to the one in the right side of Figure 2 is achieved by a positive 90° rotation around the Z-axis of the orientation depicted in the left side of that figure.

2.1.3 Rotation around the X- *and* Y-axes

The interpretation of the signals produced by the inclinometer is slightly more complicated when there is a rotation around *both* the X- and the Y-axes. Because gravity is the only signal sensed by the accelerometers, it can only report the angle of its X- and Y-axes with respect to the horizontal plane. Imagine that the X-axis is in a vertical plane. The value reported by the inclinometer (`Incl_Y`) is the angle of the X-axis *below* the horizontal plane, within this vertical plane that contains the X-axis. This holds regardless of the orientation of the Y-axis. Similarly, the reported `Incl_X` is the angle of the Y-axis *above* the horizontal plane. This is the only unconditional interpretation of these two inclinometer signals!

To visualize a two-axis rotation, start with a rotation around the Y-axis as shown in Figure 2 (left side). The Y-axis is horizontal throughout this rotation. Next, rotate the inclinometer positively around its newly oriented X-axis. The Y-axis will rise above the hori-

Figure 3: An illustration of the right-hand rule of rotation.

zontal plane while the orientation of the X-axis remains unchanged. The orientation of the Y-axis is now not exactly like the one shown in Figure 2 (right side). For the same rotation θ_X, the angle of the Y-axis above the horizontal plane is now smaller than depicted in Figure 2 (right side). This become quite obvious when the initial rotation around the Y-axis is large, say $\theta_Y = 80°$. The angles that the Y-axis can make with respect to the horizontal plane, for *any* rotation around the X-axis, is now restricted to the range of $\pm 10°$. The general formulae for the angles of rotation around the X- and Y-axes are

$$\begin{aligned}\theta_Y &= \texttt{Incl\_Y} = \sin^{-1}\left(\frac{-a_X}{g}\right) \\ \theta_X &= \sin^{-1}\left(\frac{\sin[\texttt{Incl\_X}]}{\cos\theta_Y}\right) = \sin^{-1}\left(\frac{\sin[\texttt{Incl\_X}]}{\cos[\texttt{Incl\_Y}]}\right).\end{aligned} \tag{5}$$

When the rotation θ_Y is small, $\theta_X \to$ `Incl_X`. When there is rotation around more than one axis, the order of the rotation is important for the interpretation of the inclinometer signals, but this topic is beyond the scope of this note.

2.2 Ambiguity Angles

The outputs from the inclinometer have points of ambiguity. If we rotate the inclinometer around its horizontal Y-axis by 90°, the X-axis points straight down (Figure 2, left side). The inclinometer will correctly report `Incl_Y` $= 90°$. However, rotations of 89° and 91° produce identical reports of `Incl_Y` $= 89°$. The same is true for a 90° rotation around a horizontal X-axis (Figure 2, right side). Thus, the angles reported from the inclinometer are restricted to the range of $\pm 90°$.

2.3 Why use the ADIS inclinometer?

Initially, RSI instruments carried a three-axis linear accelerometer. The nomenclature 'linear' means that the accelerometer responds down to zero-frequency, and so it can be used to measure both the angles of rotation (like the ADIS) and vibrations up to $\sim$100 Hz. However, even the highest-quality linear accelerometers suffer from a temperature-induced zero-point shift. That is, if their X- and Y-axes are locked into the horizontal plane, then the readings can vary by $\sim \pm 1°$ over the oceanic temperature range. For VMPs this level of error is acceptable, but not so for gliders.

The ADIS inclinometer performs far better at low-frequencies than a linear accelerometer. It is calibrated at the factory (Analog Devices) over a range of temperature and its reports are corrected internally for the effects of temperature with the help of an internal thermometer. The internal temperature is reported by the `Incl_T` output. The manufacturer claims an accuracy of $\pm 0.1°$ for inclinations up to $\pm 30°$. This is incredibly good. The accuracy degrades for larger inclinations and is quite poor near the ambiguity angles of $\pm 90°$.

Another limitation of the ADIS inclinometer is that its internal electronics are limited to a full-scale range of $\pm 1.7g$. Shocks and vibrations beyond this range induce non-linearity, and the angular reports may be erroneous. This is usually not a problem with VMPs and gliders because these are very low-vibration platforms. However, this was a problem with the original Nemo float because its MicroRider was not well cushioned.

2.4 ADIS inclinometer summary

- The inclinometer measures the angles of its X- and Y-axes with respect to the local horizontal plane within the vertical planes that contain these axes. The angle of the inclinometer Y-axis *below* the horizontal plane is reported by `Incl_X` . The angle of the inclinometer X-axis *above* the horizontal plane is reported by `Incl_Y` . Both angles are in units of degrees.
- The reports from the inclinometer can be interpreted as rotations around the X- and Y-axes using eq. (5).
- The claimed accuracy of the ADIS-16209 is $\pm 0.1°$, for angles in the range of $\pm 30°$, due to a temperature and other types of internally computed corrections.
- Readings are restricted to the range of $\pm 90°$ and quality is poor near the extrema.

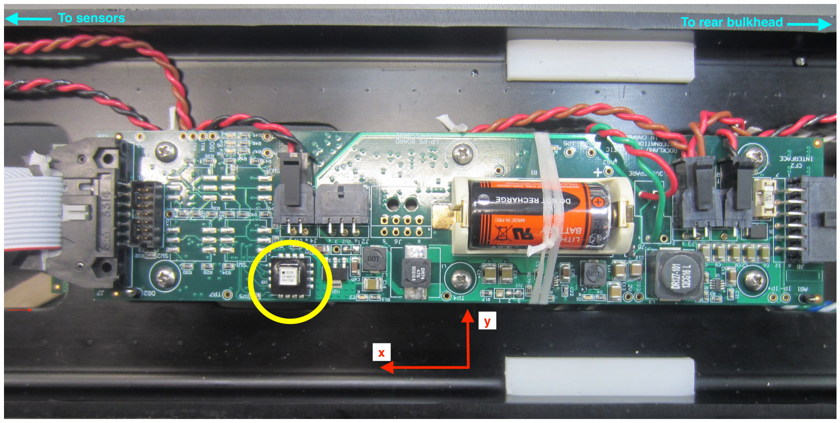

Figure 4: An upward looking view of the power-supply board that carries the ADIS inclinometer (yellow circle), and the MicroRider coordinate system (red arrows with lower-case x and y labels). The power-supply board is usually mounted on the 'underside' of the black frame when the MicroRider is oriented as shown in Figure 6. The instrument nose cone and the microstructure sensors are to the left (the x-direction). The port side is in the y-direction.

3 RSI Instruments

The interpretation of the inclinometer signals depends on how the inclinometer chip is oriented on its circuit board (Figure 4) and on how this board is oriented within an instrument. There are many possible orientations and the interpretation is simplified if one or more of the inclinometer axes coincides with the axes of the instrument.

Nearly all instruments (VMPs, MicroRiders, and MicroCTDs) have their power-supply board mounted to an internal frame so that the board is on the 'underside' when these instruments are placed horizontally on a bench, with the pressure port (or the ON/OFF magnet) on the top (Figures 5 and 6). Thus, the view of Figure 4 is upwards looking.

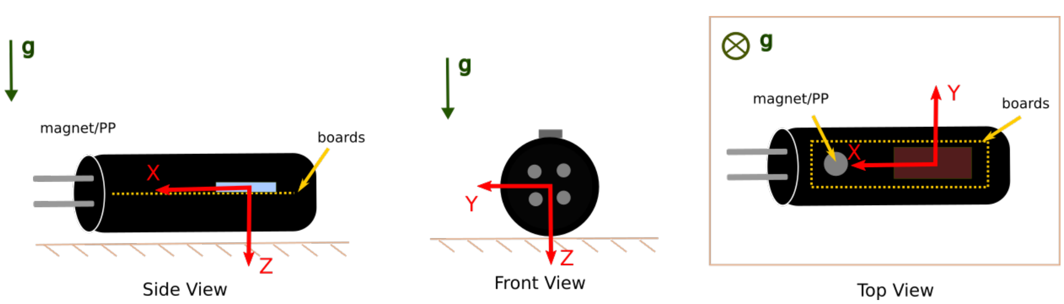

Figure 5: The coordinate system of an inclinometer when it is in an RSI instrument that is resting horizontally on a bench (red arrows). The gravity vector, **g**, is green, and the magnet or pressure port (PP) is on top.

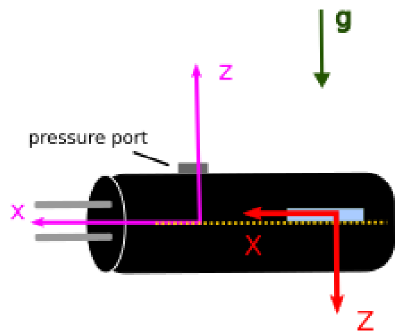

Figure 6: The coordinate system of a horizontal profiler (x,y,z) is shown by the pink vectors. The inclinometer coordinate system (X,Y,Z) is shown in red.

3.1 Horizontal and quasi-horizontal profilers

Horizontal and quasi-horizontal (designated, hereafter, by just horizontal) profilers include gliders, AUVs and the Nemo floats. A MicroRider is usually mounted on these vehicles. The coordinate system used by RSI for these instruments has x pointing forward in the direction of travel, y pointing athwartship and to port (towards the left when looking in the direction of travel), and z orthogonal to these axes and pointing approximately upwards (Figure 6). These coordinates are often called the 'body frame' or the 'instrument frame'.

The x- and X-axes coincide for horizontal profilers. However, because the power-supply board is mounted on the underside of the frame, the inclinometer Y-axis points to starboard (instead of to port) and the Z-axis points nominally downwards. Thus, `Incl_Y` reports the correct rotation around the body y-axis, but the report from `Incl_X` must be negated so that it correctly represent a rotation around the x-axis (Table 2).

The entries that must be placed into the configuration file of a MicroRider when it is used on a horizontal profiler are shown in Figure 7.

The signals produced by the inclinometers (after conversion into physical units) for pitch and roll related rotations are illustrated in Figure 8. When the front-end of the MicroRider points down (such as during a glider dive) `Incl_Y` > 0 (Figure 8, upper left). Engineers usually consider this to be a negative pitch, but it is correctly signed to indicate a positive rotation around the body y-axis ($\theta_y > 0$). A negative rotation around the y-axis raises the nose of the MicroRider (upper right). With the x-axis of the MicroRider approximately horizontal, a positive rotation around the x-axis raises the port side and brings the y-axis above the horizontal plane, and the Y-axis below the horizontal plane (Figure 8,

Channel	Acceleration Component	ADIS signal	Inclination body frame
40	a_X	`Incl_Y`	θ_y
41	a_Y	`Incl_X`	-θ_x

Table 2: The signals reported by the inclinometer when it is used on a horizontal profiler.

```
; ----------------
; The ADIS precision inclinometer with built in thermometer
[channel]
; instrument dependent parameters
id      = 40
name    = Incl_Y
type    = inclxy
; sensor dependent parameters
coef0   = 0
coef1   = 0.025
units   = [deg]

[channel]
; instrument dependent parameters
id      = 41
name    = Incl_X
type    = inclxy
; sensor dependent parameters
coef0   = 0
coef1   = -0.025
units   = [deg]
```

Figure 7: The inclinometer related entries in a configuration file of a MicroRider mounted on a horizontal profiler. The sign of `coef1` for `Incl_X` is negated. Its magnitude converts the raw inclinometer data in units of degrees.

lower left). This produces a positive report for `Incl_X` because `coef1` is negated in the configuration file (Figure 7). Engineers usually consider this a positive roll.

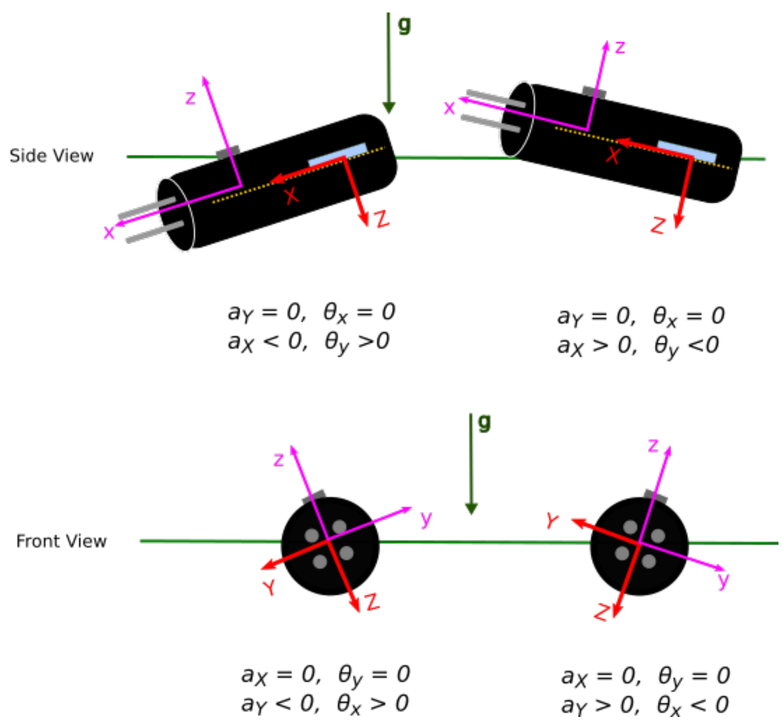

Figure 8: The orientations of a horizontal profiler and the resultant acceleration and inclination signals. Upper panel – pitch motions or rotations around the body y-axis. Lower panel – roll motions or rotations around the body x-axis.

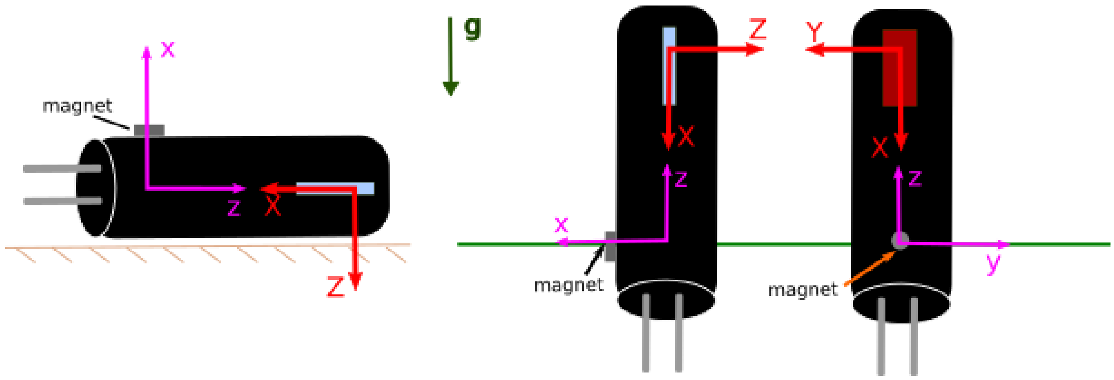

Figure 9: The coordinate system for a vertical profiler (x,y,z) is shown by the pink vectors. The inclinometer coordinate system (X,Y,Z) is shown in red. The instrument is shown in its horizontal (left) and vertical (centre and right) positions. The green line represents the horizontal plane.

3.2 Vertical Profilers

For a vertical profiler, the RSI body coordinate system has the z-axis pointing from the front bulkhead to the rear bulkhead, the x-axis goes through the ON/OFF magnet (or the pressure port) and the y axes is defined to 'port', such that the coordinate system is right handed (Figure 9, right side). However, when the VMP is resting horizontally on the bench and with its ON/OFF magnet on top (Figure 9, left side), the inclinometer is oriented exactly like it is in a MicroRider (Figure 6).

When the VMP is in its operating orientation – i.e. vertical – the instrument has been rotated (from its bench orientation) by 90° around its y-axis. The inclinometer X-axis is pointing straight down and it reports `Incl_Y` $= 90°$. The `Incl_Y` reports will be ambiguous because they cannot exceed 90°. Thus, only large angular deviations of the VMP z-axis away from vertical – ones that makes the `Incl_Y` significantly smaller than 90° – will be meaningful. Such angular deviations do occur when a VMP is being pulled back to the surface, and when there is insufficient slack in the tether during a profile.

However, when the VMP is in its operating orientation, both the inclinometer Y- and the instrument y-axes are still in the horizontal plane. `Incl_X` will report the inclination of the Y-axis out of the horizontal plane, and do so with the specified accuracy of $\pm 0.1°$. A positive rotation around the x-axis points the Y-axis down (Figure 9, right side) which produces a negative signal in a_Y. If we use the same negation of the coefficient `coef1` for `Incl_X` that is shown in Figure 7, then the sign of `Incl_X` is correct for the VMP. Thus, the same inclinometer parameters serve both a MicroRider and a VMP.

Some possible orientations of a VMP during a profile are summarized in Figure 10.

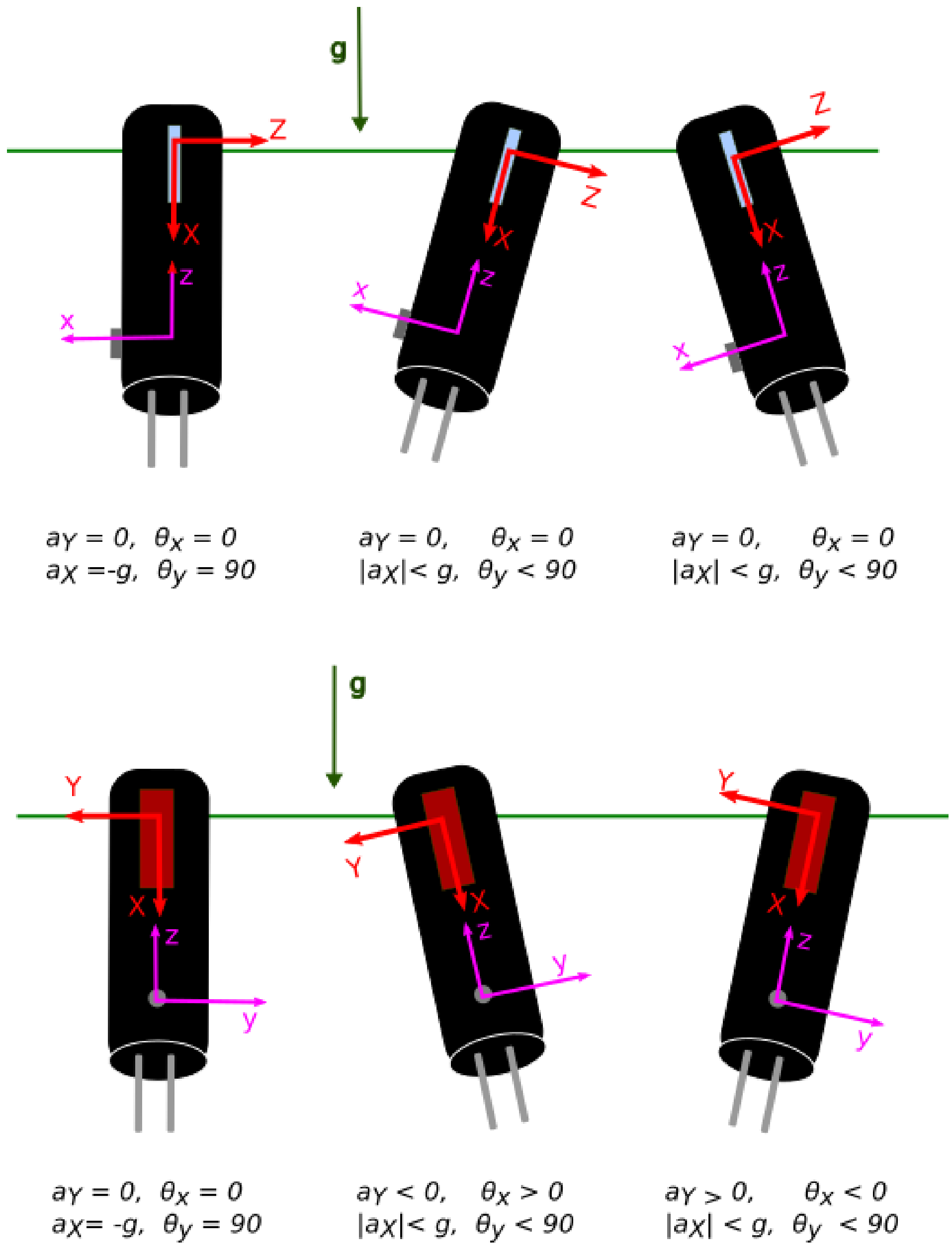

Figure 10: Some orientations of a vertical profiler and the corresponding acceleration and inclination signals. Upper panel – rotation around the body y-axis. Lower panel – rotation around the body x-axis. Upper(lower)-case symbols represent the inclinometer (body) frame.

Cleary, we cannot use eq. (5) to determine the rotation around the x-axis of a VMP because the rotation around the y-axis is near the ambiguity point of 90°. You have to consider the orientation of a VMP to first be a rotation around the x-axis followed by a rotation around the y-axis. That is

$$\begin{aligned}\theta_x &= \texttt{Incl\_X} = \sin^{-1}\left(\frac{-a_Y}{g}\right) \\ \theta_y &= \sin^{-1}\left(\frac{\sin[\texttt{Incl\_Y}]}{\cos\theta_x}\right) = \sin^{-1}\left(\frac{\sin[\texttt{Incl\_Y}]}{\cos[\texttt{Incl\_X}]}\right) \quad .\end{aligned} \tag{6}$$

3.3 RSI Inclinometer Summary

Table 3 summarizes the measurements acquired by the inclinometer in a typical RSI instrument, using the configuration parameters of Figure 7. The upper-case letters represent the inclinometer coordinate system and the lower-case letters represent the body coordinate system.

Channel `id`	Signal Measured	Inclination Reported	HMP	VMP
40	a_X	`Incl_Y`	θ_y	θ_y[2]
41	a_Y	`Incl_X`	θ_x	θ_x
42	T		θ_T	θ_T

Table 3: The signals reported by the ADIS-16209 inclinometer and their interpretation using the configuration information of Figure 7. θ_T is the internally derived temperature.

[2] But this angle will be near 90° for a vertical profiler

4 Inclinometer Bench Data

4.1 Bench test example

A data file was collected using a VMP, where the instrument started horizontal on a table with the magnet on the top (Figure 6), using the configuration parameters of Figure 12. The value of `coef1` for `Incl_X` was intentionally *not* negated for this test in order to minimize confusion. The various changes of orientation are summarized in Table 4.

Label	Time range [s]	Description	Ch. 40 [○]	Ch. 41 [○]
A	0 - 30	Flat on the table, magnet up	0	0
B	35 - 45	Nose Down	20	0
C	52 - 62	Nose Up	-10	0
D	63 - 93	Flat on the table, magnet up	0	0
E	95 - 105	Roll to starboard/right	0	-60
F	110 - 120	Roll to port/left	0	45
G	120 - 150	Flat on the table, magnet up	0	0
H	170 - 180	Vertical, nose down	90	0
I	185 - 195	Vertical, rotated about X	90	0
J	215 - 225	Vertical, swung about Y	80 to 90	0
K	235 - 245	Vertical, swung about Z	80 to 90	±5

Table 4: Summary of datafile. Starboard/port reference given as if the sensors are at the front.

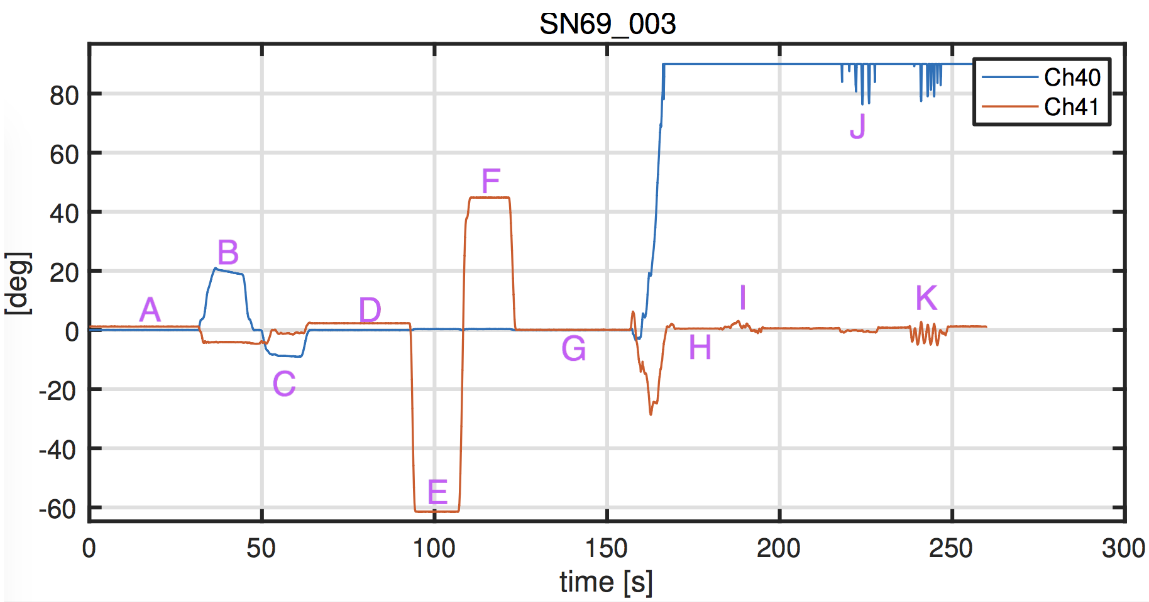

Figure 11: The reports from the inclinometer during the test conditions given in Table 4

```
; The ADIS precision inclinometer with built in thermometer
[channel]
; instrument dependent parameters
id      = 40
name    = Incl_Y
type    = inclxy
; sensor dependent parameters
coef0   = 0
coef1   = 0.025
units   = [deg]

[channel]
; instrument dependent parameters
id      = 41
name    = Incl_X
type    = inclxy
; sensor dependent parameters
coef0   = 0
coef1   = 0.025
units   = [deg]
```

Figure 12: The configuration file used for collecting the bench data shown in Figure 11. The value of `coef1` for `Incl_X` is *not* negated.

4.2 Doing your own bench test

If you have any doubt about the signals produced by the inclinometer, you can check the sensor and your configuration file using the orientation shown in Figure 6 as the starting point, and replicate the orientations of steps A–G shown in Table 4. There are several ways to see the data fairly promptly while you are changing the orientation of your instrument. For internally recording instruments, you can do one of the following:

- Use the `-cal` option of `odas5ir` to get a report of the raw data for a selected channel, or for all of the channels that are listed in your configuration file.
- Use `odas5ir` with the `-D` (verbose) option to see a live stream of raw data.
- Collect data using `odas5ir` and view the file using the tools in the ODAS Matlab Library.

For real-time transmitting instruments you can do one of the following:

- Use the calibration menu of `ODAS-RT` to see the raw data, and their statistics, for every channel `id` in your configuration file.
- Use the 'connect' option to see a live stream of data. But, you **must** click on the raw-data button so that the data are **not** converted into physical units [3].
- Collect data using `ODAS-RT` and view the file using the tools in the ODAS Matlab Library.

The first item that you should check is the channel `id` assignments for the inclinometer. You should lower and raise the front end of your instrument by a substantial amount (30° to 45°), while rotating it as little as possible around its principal (long) axis. `Incl_Y` (typically `id`=40) should respond with very significant changes of value and of sign. If the

[3]There is a recently discovered bug in ODAS4RT that negates the sign of both inclinometer signals with respect to the specifications in the configuration file.

changes are reported by `Incl_X` (typically `id`=41), then the channel assignments are wrong, and you should correct this by switching the channel `id` numbers for the inclinometer in the `setup.cfg` file. It is also possible that the firmware has been mis-programmed (see section 5.1 for more information). Next, retest the changes.

The second item to check is the sign of the values reported by `Incl_Y` . Nose down should be positive. If nose-down gives a negative report for `Incl_Y` , then negate `coef1` in your configuration file.

The testing of `Incl_X` is similar to that of `Incl_Y` . You should now have the correct channel `id` assignments, and will look at the reports for rotations around the nearly horizontal principal axis. A substantial positive (negative) rotation (while keeping the principal axis as close to horizontal as possible) should produce a positive (negative) raw report from `Incl_X` . If the reverse is true, negate the value of `coef1` in the configuration file.

You should get the correct response on each signal from the inclinometer if the following three items are true:

1. the configuration file contains the channel assignments and the coefficients that are shown in Figure 7, and
2. the inclinometer firmware is a correct version, and
3. the power-supply board is oriented in its standard position within a VMP and/or a MicroRider.

5 Issues

5.1 Firmware issues

On, or about, 2017-10-18, the firmware in the power-supply board (P050) was modified to strip out the `new_data` flag and the `error` flag in the 16-bit numbers reported by the ADIS inclinometer. The `new_data` flag is the most significant bit (bit-15) and should always equal 1. The error flag is in bit 14 and should always be 0. The remaining 14 bits are the signed data values in two's-complement form. Thus, every raw datum is a negative number, if the `new_data` flag is set, which is always the case with a properly functioning inclinometer. This makes it difficult to read the raw data from the inclinometer. The ODAS Library provides the function `adis` to strip the flags, and to convert the data into properly signed two's-complement 16-bit numbers, and to save the flags, if they are not of the correct value. The numbers are then easily read by people, and multiplying them by 0.025 converts them into angles in units of degrees. Starting from 2018-10-18, the flags are stripped in firmware because the flags have never deviated from their expected values, and the stripped raw data are read and interpreted more easily.

Along with the change to stripping the flags in the firmware, the channel assignment for `Incl_X` and `Incl_Y` were inadvertently reversed. This erroneous channel assignment was not noticed until 2018-09-12 and was not corrected in the production of instruments until about 2018-12-01. Thus, there is a time span of over twelve months when the channel identification of the ADIS inclinometer is reversed. Customers that have these instruments must change the assignments in their configuration file. This correction is important for all gliders because the rotation around the y-axis is used to determine the pitch of the glider and, along with the rate of change of pressure, is used to estimate the speed of profiling. For users of the VMP the change is important only for profile visualization. That is, the kinematics figure produced by `quick_look` draws a profile of `Incl_X` to provide an indication of how much the VMP is swinging away from the vertical axis.

All instruments that are returned to RSI, for service or other reasons, will have the firmware updated. Clients must remember to revert the channel assignments in their configuration file back to their historical correct value, after the update.

5.2 Software issues

While we were testing the inclinometer, we noticed that the values of `Incl_X` and `Incl_Y` are negated by the real-time data display in `ODAS-RT`. We have not yet identified the reason for this bug. However, this certainly complicates the interpretation of the values reported by the inclinometer. If you click on the `raw data` button, the values are reported correctly. Thus, we have to be careful about using the real-time display of `ODAS-RT` for examining the inclinometer data, until this bug is fixed.

The processing of the inclinometer data by the ODAS Matlab Library is correct and follows exactly the specifications in the configuration file.

5.3 Hardware issues

There are currently two known problems with the ADIS inclinometer that are of a hardware nature.

5.3.1 Mechanical connection

The mechanical connection of the inclinometer may become an issue following severe shock or vibrations, which may occur during shipping. This could result in an intermittent or broken connection between the inclinometer and the circuit board. Always confirm inclinometer functionality before each deployment and contact Rockland Support if you have any concerns.

5.3.2 Frame warpage

The rear end-cap of RSI instruments is frequently secured by an acorn nut that pulls together the front bulkhead, the pressure tube and the rear end-cap. The recommended torque on the acorn nut is specified in the Instrument User Manual [4]. The nut threads into a rod that protrudes through the rear end-cap. The rod is attached to the frame that holds the electronics, and this frame is secured to the front bulkhead. Excessive torque on the acorn nut deforms the frame. The initial deformation is a rotation of the frame around its principle axis – the x-axis of a MicroRider, for example. This deformation induces a positive report from `Incl_X` even when the instrument is level and has the pressure port at top dead centre. A positive twist is expected because the the nut has right-hand threads. The angular rotation of the inclinometer can be as large as 7°. Extremely excessive torque induces a bowing of the frame and this biases the reports from `Incl_Y`. It is unlikely that this has ever occurred with a MicroRider, but the bowing was noticed in a test conducted with a transparent pressure tube.

You can check if the frame is warped by placing the MicroRider (or a VMP) into its starting position (Figure 6) and carefully rotate it until the magnet / pressure port is as close to top centre as possible. With a reasonable 'eye', the port will be with about ±2°. If the report from `Incl_X` exceeds this value, the frame may be warped. If it is warped, reduce the tension on the acorn nut and carefully re-tighten to the specified torque.

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[4] For a MicroCTD, MicroRider1000 and VMP-250, the recommended torque is 25 in – lb. For other instruments, please consult your Manual or support@rocklandscientific.com