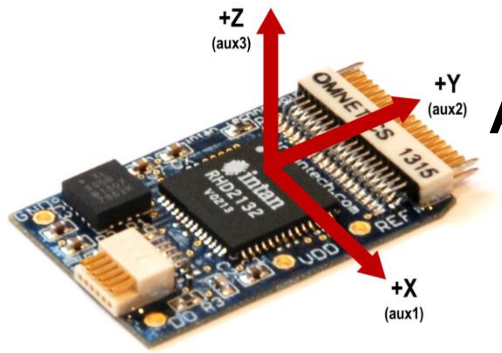
RHD

Application Note: Accelerometer Calibration



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Q:

The Intan RHD headstages with accelerometers return voltages proportional to acceleration on three axes. How can these signals be calibrated to yield precise acceleration values, and how can the sensor's response to gravity be distinguished from its response to dynamic motion?

A:

Some Intan RHD headstages use Analog Devices ADXL335 3-axis accelerometers to sense both movement and orientation with respect to gravity. The analog signals from the ADXL335 accelerometer have zero-*g* bias levels around 1.7 V, though this can vary by several hundred millivolts between axes and from chip to chip. The sensitivity of the accelerometer is approximately 340 mV/*g* (where 1 *g* = 9.81 m/s^2), but this can vary between 270 mV/*g* and 390 mV/*g*. Both the zero-*g* offset and the sensitivity of each axis on each sensor must be characterized to permit accurate conversion from voltage to acceleration.

The accelerometer responds both to movement and to the gravity vector. When the headstage is resting flat as shown in the photo above, the accelerometer will return +1 *g* on the Z axis. If the headstage is flipped upside down and placed on a flat surface, the accelerometer with return -1 *g* on the Z axis. By recording accelerometer data in each of these orientations, the Z axis may be calibrated.

For example, we recorded a few seconds of data from an RHD headstage with the device flat on a level surface as shown in the photo. The data from the Intan GUI software was loaded into MATLAB, and the average of the Z axis sensor (the **aux3** signal) was calculated as follows:

```
>> mean(aux_input_data(3,:))
```

This returned a value of 2.1218 V. This process was repeated with the headstage upside down on a level surface, and the mean value of **aux3** signal was measured to be 1.4282 V. Since the difference in (static) acceleration between these two configurations is precisely 2 *g*, we can calculate the sensitivity of the Z accelerometer on this headstage as:

$$(2.1218\text{ V} - 1.4282\text{ V}) / (2\ g) = 0.3468\text{ V}/g.$$

The zero-*g* bias level may be found by averaging these two voltages:

$$(2.1218\text{ V} + 1.4282\text{ V}) / 2 = 1.775\text{ V}.$$

Using these two parameters, the **aux3** voltage may be converted to Z acceleration easily:

```
>> aZ = (aux_input_data(3,:)-1.1775)/0.3468;
```

This process can be repeated for the X and Y axes by orienting the headstage so that these axes are aligned with gravity.

It should be noted that both the zero-*g* bias level and the sensitivity of the accelerometer are linearly proportional to the headstage supply voltage. Although the supply voltage is regulated to 3.5 V on the RHD USB interface board and recording controllers, there will be some voltage drop across long SPI interface cables, so calibration should be performed using the same SPI cable length that will be used during actual data collection.

Alternatively, the supply voltage may be recorded during accelerometer calibration and again during actual experiments, and the accelerometer calibration parameters could be scaled to account for any variation in mean supply voltage.

For more detailed information on the accelerometer, please consult the ADXL335 datasheet from Analog Devices (www.analog.com). However, note that the specifications listed in this datasheet assume a supply voltage of 3.0 V, while the supply voltage in the RHD USB interface board or recording controller is likely to be higher than this.

Distinguishing Acceleration from Gravity

Accelerometers such as the ADXL335 sensor sense both dynamic acceleration due to movement and static acceleration due to gravity. The sensor returns a vector that can be written as:

$$\mathbf{a}_{\mathbf{sensor}} = \mathbf{a}_{\mathbf{dynamic}} + \mathbf{a}_{\mathbf{gravity}}.$$

When the accelerometer is at rest, $\mathbf{a}_{\mathbf{dynamic}} = \mathbf{0}$. In this case the angle of $\mathbf{a}_{\mathbf{gravity}}$, which will always have a magnitude of 1 *g*, can be used to calculate the orientation or tilt of the sensor.

When the accelerometer is moving at a non-constant velocity, $\mathbf{a}_{\mathbf{dynamic}}$ will be added to the sensor reading. If the orientation of the accelerometer is known and fixed, then $\mathbf{a}_{\mathbf{gravity}}$ can be calculated (or measured when the sensor is at rest) and subtracted from $\mathbf{a}_{\mathbf{sensor}}$ to isolate $\mathbf{a}_{\mathbf{dynamic}}$. Unfortunately, this is rarely the case.

There is a heuristic technique that may be useful for estimating $\mathbf{a}_{\mathbf{dynamic}}$ in cases where the orientation of the accelerometer is unknown and movement is sporadic. The magnitude of $\mathbf{a}_{\mathbf{sensor}}$ is calculated as

$$|\mathbf{a}_{\mathbf{sensor}}| = \sqrt{a_{\mathrm{sensor,X}}{}^2 + a_{\mathrm{sensor,Y}}{}^2 + a_{\mathrm{sensor,Z}}{}^2}.$$

If the magnitude of $\mathbf{a}_{\mathbf{sensor}}$ is very close to 1 *g* for prolonged periods of time, it is likely that $\mathbf{a}_{\mathbf{dynamic}}$ is zero during these “rest times” (though they may also correspond to periods of movement at a constant velocity). If we assume that $\mathbf{a}_{\mathbf{sensor}}$ is equal to $\mathbf{a}_{\mathbf{gravity}}$ during these periods, then the orientation of the sensor may be updated to a new value. This estimate of $\mathbf{a}_{\mathbf{gravity}}$ is then subtracted from all accelerometer readings until the next “rest time” where it can be reassessed.

This is admittedly a crude algorithm that could be refined with physically constrained models of sensor orientation. The accuracy of this technique will depend on the frequency and severity of orientation changes, and the frequency of “rest times”.

A 3-axis accelerometer such as the ADXL335 is not a complete inertial measurement unit (IMU) because it lacks gyroscopes for measuring rotation about each axis. If the accelerometer is rotated around an axis that is aligned with the gravity vector, it will give no response. This makes positional reconstruction impossible without the aid of other sensors such as visual tracking or gyroscopes.

In most experimental settings with moving subjects, it is likely that the accelerometer signals will serve primarily as a qualitative movement marker that facilitates synchronization with video tracking systems if position information is required. In wearable applications (e.g., a prosthetic limb controller), the accelerometer signal may be more useful for determining orientation or tilt during rest periods with no dynamic movement.